22 Sep 95

MMN And P3 Auditory Evoked Potentials Within And Across Phonetic Categories

Martha Ann Stokes

AFIT Students Attending:

University of Tennessee

95-018D

DEPARTMENT OF THE AIR FORCE
AFIT/CI
2950 P STREET, BLDG 125
WRIGHT-PATTERSON AFB OH 45433-7765

Approved for Public Release IAW AFR 190-1
Distribution Unlimited
BRIAN D. GAUTHIER, MSgt, USAF
Chief of Administration

87

GENERAL INSTRUCTIONS FOR COMPLETING SF 298

The Report Documentation Page (RDP) is used in announcing and cataloging reports. It is important that this information be consistent with the rest of the report, particularly the cover and title page. Instructions for filling in each block of the form follow. It is important to *stay within the lines* to meet *optical scanning requirements.*

Block 1. Agency Use Only (*Leave blank*).

Block 2. Report Date. Full publication date including day, month, and year, if available (e.g. 1 Jan 88). Must cite at least the year.

Block 3. Type of Report and Dates Covered. State whether report is interim, final, etc. If applicable, enter inclusive report dates (e.g. 10 Jun 87 - 30 Jun 88).

Block 4. Title and Subtitle. A title is taken from the part of the report that provides the most meaningful and complete information. When a report is prepared in more than one volume, repeat the primary title, add volume number, and include subtitle for the specific volume. On classified documents enter the title classification in parentheses.

Block 5. Funding Numbers. To include contract and grant numbers; may include program element number(s), project number(s), task number(s), and work unit number(s). Use the following labels:

C	- Contract	PR	- Project
G	- Grant	TA	- Task
PE	- Program Element	WU	- Work Unit Accession No.

Block 6. Author(s). Name(s) of person(s) responsible for writing the report, performing the research, or credited with the content of the report. If editor or compiler, this should follow the name(s).

Block 7. Performing Organization Name(s) and Address(es). Self-explanatory.

Block 8. Performing Organization Report Number. Enter the unique alphanumeric report number(s) assigned by the organization performing the report.

Block 9. Sponsoring/Monitoring Agency Name(s) and Address(es). Self-explanatory.

Block 10. Sponsoring/Monitoring Agency Report Number. (*If known*)

Block 11. Supplementary Notes. Enter information not included elsewhere such as: Prepared in cooperation with...; Trans. of...; To be published in.... When a report is revised, include a statement whether the new report supersedes or supplements the older report.

Block 12a. Distribution/Availability Statement. Denotes public availability or limitations. Cite any availability to the public. Enter additional limitations or special markings in all capitals (e.g. NOFORN, REL, ITAR).

DOD - See DoDD 5230.24, "Distribution Statements on Technical Documents."
DOE - See authorities.
NASA - See Handbook NHB 2200.2.
NTIS - Leave blank.

Block 12b. Distribution Code.

DOD - Leave blank.
DOE - Enter DOE distribution categories from the Standard Distribution for Unclassified Scientific and Technical Reports.
NASA - Leave blank.
NTIS - Leave blank.

Block 13. Abstract. Include a brief (*Maximum 200 words*) factual summary of the most significant information contained in the report.

Block 14. Subject Terms. Keywords or phrases identifying major subjects in the report.

Block 15. Number of Pages. Enter the total number of pages.

Block 16. Price Code. Enter appropriate price code (*NTIS only*).

Blocks 17. - 19. Security Classifications. Self-explanatory. Enter U.S. Security Classification in accordance with U.S. Security Regulations (i.e., UNCLASSIFIED). If form contains classified information, stamp classification on the top and bottom of the page.

Block 20. Limitation of Abstract. This block must be completed to assign a limitation to the abstract. Enter either UL (unlimited) or SAR (same as report). An entry in this block is necessary if the abstract is to be limited. If blank, the abstract is assumed to be unlimited.

MMN AND P3 AUDITORY EVOKED POTENTIALS WITHIN AND ACROSS PHONETIC CATEGORIES

A Dissertation Presented for the

Degree of

Doctor of Philosophy Degree

The University of Tennessee, Knoxville

Martha Ann Stokes

August 1995

DISCLAIMER

This dissertation was written by Captain Martha Ann Stokes while a student at the University of Tennessee studying for a Ph.D. in Speech and Hearing Science. The views expressed in this dissertation are those of the author and do not reflect the official policy or position of the Department of the Air Force, Department of Defense, nor the U.S. Government.

To the Graduate Council:

I am submitting herewith a dissertation written by Martha Ann Stokes entitled "MMN and P3 Auditory Evoked Potentials Within and Across Phonetic Categories." I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Speech and Hearing Science.

Dr. Harold Peterson, Major Professor

We have read this dissertation
and recommend its acceptance:

Accepted for the Council

Associate Vice Chancellor and
Dean of the Graduate School

DEDICATION

This dissertation is dedicated to my mother, **Cynthia Katherine Stokes**, and in loving memory of my father, **Marion Stokes**. I cannot begin to thank you for making life easy, stable, and peaceful growing up. Only now with three teenagers and eighteen years of marriage do I realize the impossible task you performed. I wish I could have given my own children what I had. I love you dearly.

ACKNOWLEDGEMENTS

The Air Force views any challenge as an opportunity and I truly appreciate the opportunity to be in this academic arena over the past three years. It was the best job I have ever had. Thanks to the Air Force.

Acknowledge somehow does not begin to express the deep appreciation I have for my major professor, Dr. Harold Peterson. You laid a path and helped me every step of the way in attaining my goal. Your knowledge, humor, accessibility, turn around time, and yes even stubbornness gave me invaluable tools that led me to completion. I could not have done it without you. Your the greatest. By the way, you are not getting rid of me. I will be calling. Maybe you did too good of a job.

What can I say about my dissertation committee but I can sure pick em. Dr. Jim Thelin, you have a way of getting to the essence and verbalizing it in a clear and concise manner. Your input and support on this project and my entire program was invaluable. It is easy to figure out why all the audiology students want to work with you. Also you kept things from getting in a pucker. If you know what I mean. Dr. Anna Nabalek, I can remember one day telling you about how I screwed things up on my data input for statistical analysis and you responded by saying, "Well at least you are doing something

in order to make mistakes". This kind of positive attitude towards research and life in general is very special and I admire you a great deal. Your reputation in the research community is unsurpassed and it was my fortune to have your expertise during this project. Dr. Lubar, a special note of appreciation for accommodating my schedule two days before leaving the country. Your insight and expertise in the evoked potential and brain mapping areas added strength to my knowledge base, the defense, and future research ideas.

Max Dawson and Ron Holder, you were right. If I had any sense, I would have picked a dissertation that did not depend on equipment and I'm sure you wished I had. But of course with your capabilities, things couldn't have turned out better. Many thanks for being there each and every time (too many to count) I needed you. I am deeply grateful. You could take that sailboat to the Mississippi Coast you know.

Alexandra Ovchinnikov (Sasha), your knowledge and willingness to share it along with many, many hours of help out of the goodness of your heart will always be remembered. Thank you so much.

Thank you Dr. Ravi Krishnan for spending your time in working on speech synthesis and equipment to use as a backup, if needed. This was above and beyond the call of duty. Thanks again.

The Chancellor of The University of Tennessee and the University Computing Center are acknowledged for providing central computing facilities and services. To Don Broach, you are truly a life saver. Your time and effort in making this project and the previous one a success is greatly appreciated.

Thanks goes out to each and every subject in this study. Without you volunteering your time (and believe me, I know how valuable it is) none of this would have been possible.

To Dee Lance, I have been working for twenty years and you have been the best friend, colleague, and support one could have. Truly a comrade in arms. To Lea Helen Evans, things wouldn't have been the same without you. Thank you for your graphic creations, friendship, and sense of humor that was greatly needed over the past three years. Thanks to all of my fellow graduate students. Sticking together makes all the difference.

To the base of the entire operation, Dr. Jerry Carney, this experience has been everything that I hoped for and more. Your leadership provided the ground for success as a military out service training program that I recommend very highly. Kay Gross, he couldn't have done it without you and neither could I. Your assistance with just about everything is so much appreciated.

This work experience and environment has been exceptional. To everyone named above and the entire staff of **Audiology and Speech Pathology** at **University of Tennessee**, you are **The Best of the Best**.

ABSTRACT

The mismatch negativity (MMN) and P300 of the auditory evoked response potentials were studied within and across phonetic categories of /ba/ and /pa/ differing in voice onset time. The MMN and P300 responses were present in all within and across phonetic conditions suggesting a discrimination at both temporal areas of the ERP. There were no differences in the MMN amplitude or latency measures. P300 amplitude was found to be significantly larger for the across category conditions. These results suggest that categorical processing may not occur in the temporal domain of the MMN and may first occur in the time period of the P300. Measures of acoustic discrimination and linguistic categorization at the level of central processing are of great clinical value.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER I

INTRODUCTION

The complex process of speech perception can be viewed as a multilevel hybrid model involving perception of physical acoustic differences as well as categorization of speech-specific phonetic components. Categorical perception occurs when the continuous, variable, and confusable stimulation that reaches the sense organs is sorted out into discrete distinct categories whose members somehow come to resemble one another more than they resemble members of other categories (Harnad, 1987).

Categorical perception of consonant sounds has been studied primarily when these consonants vary along a single criterion feature, such as voice onset time or place of articulation. Behavioral studies document perceptual differences that can be linguistic or nonlinguistic depending on the stimuli. Acoustic variations are probably perceived neurologically that do not have linguistic significance in English, such as prevoicing. There are many published references of this phenomenon, (e.g. Repp (1984) that in general, speakers from different linguistic environments exhibit categorical perception for voicing contrasts that are characteristic of their languages and ignore variations that are not phonetic in their

languages (Lisker and Abramson, 1964; and Simon and Fourcin, 1978). Individual sounds are grouped into phonemic categories for linguistic processing. Allophonic variations in speech are ignored because they do not have meaning or do not provide linguistic information. In normal linguistic processing the variations within categories are not generally perceived behaviorally.

The processing of speech sounds can be tested behaviorally using discrimination procedures. Most recently the processing of speech sounds has been studied using auditory evoked potentials (AEP) procedures. With AEP procedures, differences in neural processing can be measured at different time periods after presentation of the speech stimulus. The decision as to the type of processing (i.e., acoustic or linguistic) is determined empirically. There is mounting evidence that the neural processing becomes more linguistic at successive time periods. The auditory evoked response potential (AEP) gives the investigator the advantage of directly measuring the physiological base for discrimination or perception rather than inferring the physiological representations from behavior.

The purpose of the present study was to determine the extent to which the AEP responses in successive time periods depend on the acoustic or linguistic parameters of the speech stimulus. Acoustic discrimination and categorization of stimuli is the basic model in which the data will be viewed.

REVIEW OF THE LITERATURE

This section provides a general overview of speech perception, particularly categorical perception, and late auditory evoked potentials. Studies in the area of cortical potentials and speech perception are of particular interest.

SPEECH PERCEPTION

Handel (1991) states that all perceiving comes from acoustic patterning, and all perceiving can yield both the categorization and auditory detail suggesting several levels of processing. Macmillan (1987) proposes a psychophysical model of perception which involves a sensory trace involving the immediate memory and context mode involving immediate and long term memory. The trace mode could be considered the perception of physical acoustic differences or auditory detail and the context mode would be considered the categorization of speech-specific phonetic components. These models suggest that acoustic and linguistic processing are involved in speech perception.

Categorical perception in speech specifically concerns the descriptive categories. Each speech sound can be categorized in terms of features such as voicing, nasality, manner, and place of articulation. Categorical perception of consonant sounds has been measured primarily when these consonants vary along a single criterion feature, such as voice onset time or place of articulation. Behavioral studies of categorical perception typically utilize discrimination and identification tasks. In a discrimination task, an individual compares and listens for differences between two stimuli presented in close temporal proximity. On the other hand, in an identification task or an absolute judgement task, the individual listens to acoustic stimuli one at a time and tries to connect that perceptual sound to one in his or her memory that has a particular label or category. Studdert-Kennedy, Liberman, Harris, and Cooper (1970) proposed four operational criteria for categorical perception: 1) distinct labeling categories with sharp boundaries; 2) regions or "troughs" of chance performance in discriminating stimuli drawn from the same labeling category boundary (within category); 3) discrimination performance peak at the category boundary; and 4) close correspondence between the actual discrimination performance and discrimination performance predicted from the labeling results based on the assumption of absolute categorization. A study by Liberman et.al. (1957) is a classic example of categorical perception

among voiced consonants /b/, /d/, and /g/. Categorical perception was found to occur with consonants (in vowel context) varying over single physical continua, but not when these were presented in isolation. For a complete review see Repp (1984).

Non meaningful allophonic variations in speech are ignored because they are irrelevant to the perceived message or do not provide linguistic information (Handel, 1991). Normally it is unnecessary to make fine distinctions within a category. In other words, in listening for meaning, it is of little importance to discriminate among the acoustic (within category) versions of /pa/ for example. Adults with different linguistic backgrounds exhibit categorical perception for voicing contrasts with category boundaries that are characteristic of their language (Lisker and Abramson, 1964; Simon and Fourcin, 1978).

Categorical perception does not appear to be a fixed, unalterable perceptual process but instead appears to depend on the task and on the memory and judgement of the listener (Handel, 1991). A discrimination task can be simplified and/or provide enhanced feedback about the relevant acoustic differences among events within a category, in order to "weaken" the degree of categorical perception experimentally (Handel, 1991). A simple discrimination task requires the subject to indicate if two stimuli are the same or different (AX paradigm). A more

complex task is to have the subject listen to two stimuli and then indicate if a third stimulus is more like the first or the second stimulus (ABX paradigm). There are a number of studies demonstrating listeners being able to differentiate within-category patterns with a certain degree of accuracy (Kewley-Port, Watson, and Foyle, 1988; Barclay, 1972; Carney, Widin, and Viemeister, 1977; and Macmillan, Kaplan, and Creelman, 1977). When categorical perception is found, linguistic perception, such as phonetic class, takes precedence over acoustic perception. It is a simplified style of perception that throws away subtleties in the signal (Handel, 1991). Categorical perception is virtually always utilized in natural listening situations and is a result of further linguistic processing and not a result of an inability to discriminate (Handel, 1991). "The additional processing serves, in effect, to permit listeners when perceiving the sounds of speech to listen through the acoustic characteristics of the speech signal and extract the significance of the message, which at this level of processing is the phonetic intent of the speaker" (Eimas, Miller, and Jusczyk, 1987).

Macmillan (1987) distinguished between "fixed" discrimination, in which subjects are tested repeatedly with the same pair of stimuli in a block of trials, and "roving" discrimination, in which the stimulus pairs may come from anywhere in the range of the continuum being tested. He interprets categorical perception in

terms of a psychophysical model, which has two parameters: 1) the trace parameter which is interpreted as a processing mode that compares a stimulus with the sensory trace of another stimulus and is influenced by how long the delay between the two stimuli is (presumable because of the decay of the iconic trace in immediate memory). The trace parameter contributes to fixed and roving discrimination. 2) the context parameter which is interpreted as reflecting a processing mode that compares the stimulus with its overall context (including possible "anchor" features) and is influenced by the size of the stimulus range. The context parameter contributes to roving discrimination and to identification (presumable involving short and long term efforts, respectively). His conclusion was that the continuous/categorical distinction in perception is an oversimplification, and that perception differs in how much one draws on the trace and context modes and in where and what their "anchors" are. The anchors may be extremes in a continua of stimuli or they may occur in the middle of the range, in which case there may be boundary regions of heightened sensitivity (for discrimination) and central "prototypes" (for identification).

EVOKED POTENTIALS

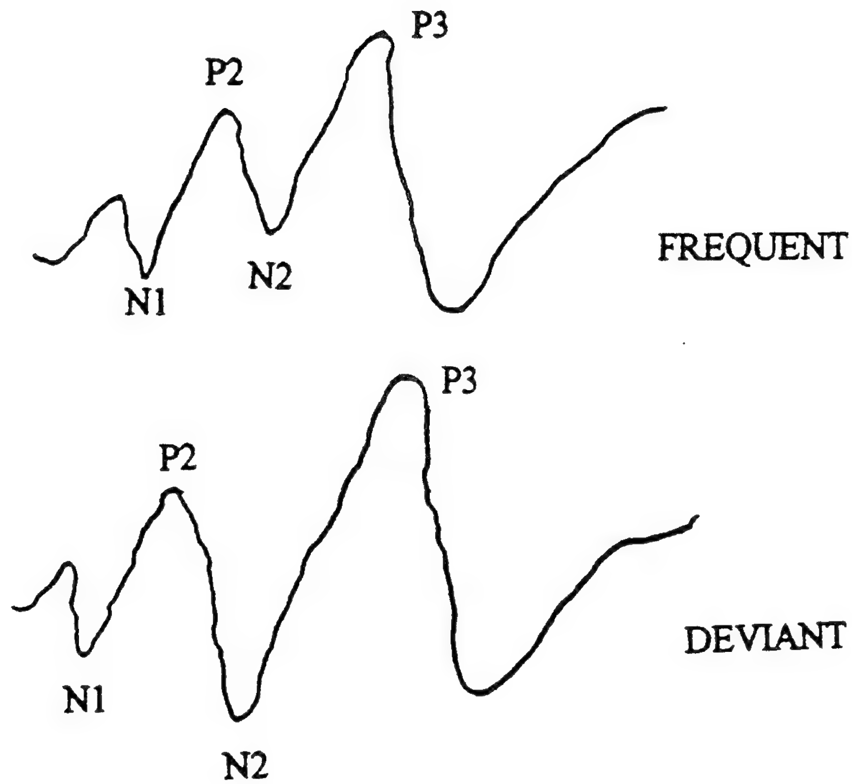
Electrophysiological measures may provide information concerning auditory and linguistic sensitivity through the use of evoked potentials. Evoked potentials are small changes in the electroencephalogram (EEG) caused by sensory stimuli that are revealed by averaging techniques (Naatanen, 1982). Using these techniques, the activity time-locked to the stimulus is preserved, and the other activity cancels itself for statistical purposes. In principle, these techniques are utilized as a means of obtaining a spatiotemporal map of the electrophysiological brain events elicited by a stimulus. By varying tasks, i.e. information processing requirements, it may be possible to detect those features of the flow of electrophysiological events that are related to different aspects of information processing (Donchin, 1984).

When measuring electrical brain activity, electrode sensors are placed in specific locations on the cortex and the electrical activity of the brain is recorded. Electrode placement is according to the 10-20 system (Jasper, 1958). The "10" and the "20" refer to percentages of distance from specific reference points on the human head. The intent is to locate recording sites over areas of the brain which

would be consistent for different laboratories and overlying the same functional locations in children or adults regardless of the size of the head.

The components of the auditory evoked potential are classified by latency. The auditory brainstem response (ABR) occurs from approximately 0 to 10 ms post onset of the stimulus and has a highly consistent pattern of waves I-VII (Hall, 1992). The middle latency component (mid-brain synaptic activity) occurs within approximately 10 to 80 ms time post onset. Peaks of interest are often labeled Na (negative a, negative going wave), Pa (positive going wave), Nb and sometimes Pb. The P and N are used to represent direction, or positive, negative characteristics and the numbers or time designation to order the waves within a period of time (Hall, 1992). These components which typically occur prior to 100 ms are usually considered exogenous (outside the stimulus parameter) and are usually not altered by the subject's psychological state. The components of the wave form that occurs from approximately 100 ms and after are considered endogenous (within the stimulus parameter) and may vary as a function of task and subject states (Rockstroh et al., 1982).

Some peaks in the waveform of the late evoked potentials that have been identified include N100(N1), P200(P2), N200(N2), and P300(P3) (Rockstroh, Elbert, Birbaumer, and Lutzenberger, 1982). (See Figure 1). The N100 is a



N1-P2 COMPLEX - STIMULUS ENCODING AND STORAGE

N2 - COMPARISON WITH STORED SIGNAL

P3 - STIMULUS VALUE
CATEGORIZATION

Figure 1. Examples of evoked potential waveforms

negative going wave occurring at approximately 100 ms. The P2 is a positive wave at approximately 200 ms. The N1-P2 complex is associated with stimulus encoding (Rockstroh et al., 1982). The N2, a negative peak following the P2 has been identified as having two component parts. One component of the N2 is related to controlled processes (N2b) and another to automatic processes (MMN) (Hoffman, 1990; Ritter, Simpson, and Vaughn, 1983). The P3 or P300 response of the event related potential is a relative positivity in the 300 ms time range post onset of the evoking stimulus and has been related to cognitive function and cognitive maturity (Chapman et al., 1979; Donchin, 1981, 1984; Pritchard, 1981; Courshesne, 1978; and Fischler, 1990). The P3 has also been divided into an automatic processing component (P3a) and a controlled processing component (P3b). The N2 and P3 will be further delineated as they are the interests of this study.

A typical procedure used in these investigations is the "oddball" paradigm. It involves the presentation of two different signals, one less frequently than the other. The P3 is elicited by rare, task relevant stimuli and considered an index of "stimulus evaluation time" (Donchin, 1984). The latency of the P3 reflects the amount of time needed to evaluate and categorize a stimulus and therefore is dependent on task difficulty (McCarthy and Donchin, 1981).

STIMULUS PROBABILITY

The N2 and P3 components may be affected by stimulus parameters as well as attentional states. A strong relationship exists between amplitude (amount of deflection) of the N2 and P3 components and probability of occurrence, so that rare events elicit larger amplitudes (Polich, 1986; Ladish and Polich, 1989; Duncan-Johnson and Donchin, 1977; and Squires, Squires, and Hillyard, 1975). Johnson (1988) suggests that probability of occurrence exerts its effects automatically, while "stimulus meaning" affects amplitude through controlled processing. This gives meaning to the original "rare, task relevant" notion for eliciting the P3 as a function of multiple processes co-occurring. Generally 20 percent probability of the rare events is used in the "oddball" paradigms and will be utilized in the present study.

ATTENTIONAL EFFECTS

Another variation in research designs with the evoked potentials is the subject's attentional state. The P3a and MMN (mismatch negativity component) have been differentiated from the P3b and N2b by attentional conditions. Sams, Aulanko, Aaltonen, and Naatanen (1990) stated that the MMN and the N2b components together form the N200 deflection in a discrimination task or a task requiring attention to the stimuli. The N2 component considered the mismatch

negativity (MMN) is also elicited by a rare stimulus against a homogenous stimulus background irrespective of whether the stimuli are being attended, and is assumed to reflect a physical mismatch between the neuronal model formed by the standard stimuli and the sensory inflow caused by the deviant stimulus (Aaltonen et al., 1987). Naatanen (1985) interpreted the MMN component as reflecting the operation of a sensory store that holds a fading trace of auditory stimuli in a manner similar to the echoic trace memory cited by Macmillan (1987). The MMN implicates memory representations which develop automatically to the physical features of the repetitive stimulus and when an input does not match with such a trace the MMN is generated. The memory traces involved appear to be those of the acoustic sensory memory, the "echoic memory" (Naatanen, Paavilainen, and Reinikainen, 1989). Squires, Squires, and Hillyard (1975) gave the same possible interpretation of the P3a indexing a basic sensory mechanism which registers any change in a background stimulus, perhaps by means of mismatching a specific neural "model" (Sokolov, 1963) established by repetition of the background. Squires et al. (1975) suggested that the P3a is very closely associated with the N2 and has been referred to as part of the N2-P3a complex (Synder and Hillyard, 1976). The P3a having a frontal-central scalp distribution and latency between 220 and 280 ms and the P3b occurring around 300 ms with a

posterior distribution (Squires et al., 1975). The P3b and second component in the N2 range also respond to mismatch but appear to be discrete from the P3a and MMN in that this variation of the wave occurs for attended stimuli and is sensitive to phonological and semantic deviations, i.e. they are not dependent on deviation from a set of background stimuli, but rather indexes deviation from a centrally maintained expectancy (Hoffman, 1990). This could be compared to our previous citing by Macmillan (1987) reflecting the processing mode that compares the stimulus with its overall context or central "prototypes." Because both processing phenomenon produce a P3, differentiation may be difficult and delineated only through topographic recording and habituation. Automatic processes, such as the MMN would show a gradual 'sharpening' of sensory information (Naatanen, Schroger, Karakas, Tervaniemi, and Paavilainen, 1993). Ivey and Schmidt (1993) indicated that the P300 complex decreased in amplitude as a result of repeated stimulation in an oddball paradigm. The P3a has not been studied extensively as an independent component and the P300 is seldom characterized as having two discrete peaks representing automatic and controlled processes.

The MMN is elicited independent of attention (Alho, Sams, Paavilainen, Reinikainen, and Naatanen, 1989; Sams et al., 1990; and Naatanen, 1990). If the subject is instructed to attend, there is the overlapping N2b component along with

the MMN to be considered. "Task relevance" was suggested as a criterion for elicitation of the P300 as a result of a majority of studies which used an "ignore" condition and in which subjects actively performed a task unrelated to the stimulus where no P3 was produced (Courchesne et al. 1975; Ford et al., 1976; Hillyard et al., 1971; and Squires, Hillyard, and Lindsay, 1973). Polich (1986) suggests that fluctuation in attention effects the amplitude component of the P3 in a two tone "oddball" but P3 latency has minimal variation. Sklare and Lynn (1984) also found subjects' attention to the stimuli effected the P3 amplitude. Rappaport et al. (1990) on the other hand, found latency shortest when the subjects were attending by counting the infrequent stimulus, later in a passive condition and the longest in a control condition, suggesting subjects' attention to the stimuli effected the latency of the P3. Reuter and Linke (1989) found a very late P3 and a MMN in coma patients with a score of 7 (severe rating) on the Glascow Coma Scale. Amplitude differences were not delineated.

These studies did not differentiate the P3 into P3a and P3b but Reuter and Linke (1989) stated that the P3 found in the coma patients had a posterior rather than frontal distribution of responses. Donchin (1978) pointed out that passive tasks provided no performance measure, and that it was not possible to assess independently the extent to which the subjects actually ignored the stimuli.

The MMN and P3 have been elicited by changes in frequency, intensity, and duration of auditory stimuli (Adler and Adler, 1991; Hari et al., 1984; Kaukoranta et al., 1989; Naatanen et al., 1978; Naatanen, Paavilainen, and Reinikainen, 1989; Paavilainen, Jiang, Lavikainen, and Naatanen, 1990; and Polich, 1989). The reasons for the changes in P3 values with variation in auditory stimulus variables most likely stem from stimulus evaluation processes (Donchin et al., 1986). Polich (1989) studied frequency, intensity, and duration as determinants of P300 elicited by auditory stimuli. In that study, Polich noted that all stimulus pairs were easily discriminated behaviorally. He found that variation in frequency, intensity, and duration of auditory stimuli can produce small but reliable P3 values.

Since the MMN has been associated with "echoic memory", interstimulus interval (ISI) has been shown to effect this component, i.e. an increase in ISI will attenuate the MMN amplitude (Mantysalo and Naatanen, 1987). The MMN decays rapidly with interstimulus intervals longer than two seconds (Naatanen et al., 1989).

There is no invariably correct number of stimulus repetitions in AER measurement (Hall, 1992). A typical number of stimuli used in studies of the MMN is 1200 and for the P3 usually 250 stimuli or less are used. Naatanen et al.

(1993) suggests that a large number of stimuli used in obtaining the MMN will result in a gradual 'sharpening' of sensory information encoded in the memory trace. The P3, on the other hand, has been suggested to habituate with an increasing number of stimuli (Ivey and Schmidt, 1993). Also the larger the signal and/or the smaller the amount of noise , the fewer repetitions are necessary, and vice versa (Hall, 1992).

In summary the psychological constructs relating to the auditory evoked response potentials (AERP's) remain speculative. The MMN (mismatch negativity) component of the auditory evoked potential has been identified as reflecting a mismatch to a sensory trace held in short term memory (Naatanen, 1985; Naatanen, Paavilainen, Alho, Reinidainen, and Sams, 1989; Schroger, Naatanen, and Paavilainen, 1992; Winkler, Reinikainen, and Naatanen, 1993). This component has been evident using stimuli with small acoustic deviations not readily identified behaviorally and is considered an automatic process (Alho, Huotilainen, Tiitinen, Limoniemi, Knuutila, and Naatanen, 1994; Naatanen and Gaillard, 1983). The P300 response of the evoked potentials has been related to cognitive function (Chapman et al., 1979; Courshesne, 1978; Donchin, 1981, 1984; Fischer, 1990; and Pritchard, 1981) and is elicited by rare, task relevant stimuli (Donchin, 1984). Task relevance may involve categorization or linguistic

processing. A P3a component has been suggested and considered the result of a basic sensory mechanism (Donchin, 1984; Snyder and Hillyard, 1976; and Squires et al., 1975) dependent on a deviation from a set of background stimuli.

LATE POTENTIALS AND CATEGORICAL SPEECH PERCEPTION

Electrophysiological measures have been used to study speech perception with various paradigms, recording sites, stimuli, and component areas of interest. Molfese (1978) studied perception of consonant-vowel speech syllables varying along a continuum of voice onset times from /ba/ to /pa/. The behavioral task indicated that subjects identified speech syllables with voice onset time (VOT) values of +0 and +20 ms as /ba/, and sounds with VOT of +40 and +60 ms as /pa/. Molfese recorded evoked potentials from the T3 (left temporal) and T4 (right temporal) regions of the 10-20 system from sixteen young adults. The paradigm was equiprobability of occurrence for each voice onset time, i.e. *not* an "oddball paradigm". A Principal Components Analysis (PCA) was performed on the averaged waveforms. This statistical procedure involves computing a correlation matrix for all variables based on the digital transformation of the

waveform. The areas of the waveform that have communalities form factors. The factor loadings are the standaridized regression coefficients in the multiple regression equation with the original variable (e.g. VOT) as the dependent variable and the factors (range of time in the waveform) as the independent variables. Results indicated that factor 1 in a range around 430 ms differentiated between all voice onset times, both within and across the phoneme boundary. This was interpreted as an acoustic or nonlinguistic discrimination. Both hemispheres were actively involved in processing information during the task, at some intervals very similar and others quite different. Molfese noted that the distinction between the voiced and unvoiced stimuli occurred in the right hemisphere.

Molfese and Hess (1978) recorded AEPs from the left and right temporal regions of twelve nursery school aged children in response to a continuum of VOT from /ka/ to /ga/. Results indicated one AEP component at 440 ms from the right hemisphere varied systematically as a function of phoneme category but did not change when elicited by VOT values from the same category. Another factor also discriminated between VOT values along phoneme boundaries, however, in contrast to adults, this component was detected at recording sites over both hemispheres.

Ahonniska, Cantell, Tolvanen, and Lyytinen (1993) studied the psychophysiological correlates of ear advantage manifested in the ERP using monaural and dichotic syllables (/pa/, /ta/, and /ka/). The most consistent finding was that subjects which exhibited a right ear advantage (REA) showed larger positive ERP deflections over the left hemisphere (maximal at T5) and subjects demonstrating a left ear advantage (LEA) showed larger positive ERP deflections over the right hemisphere (maximal at T6) both at the latency range of 320-340 ms.

Kraus, Mcgee, Sharma, Carrell, and Nicol (1992) investigated the mismatch negativity potential in response to consonant-vowel syllables /da/ and /ga/ in children and adults. An oddball paradigm was used and the MMN was recorded from the Fz (frontal zenith) location. Analysis involved subtracting the averaged wave for the frequent stimuli from the infrequent or deviant stimuli and performing T-tests on latencies and amplitudes for the component identified as the MMN in the difference wave. Results indicated that the MMN was detectable in all of the adult and school-aged subjects with no significant differences between the children and adults. The authors conclude that the MMN is an acoustic response that does not require subject attention and appears to be mature in school-aged children.

Sharma, Kraus, Mcgee, Carrell, and Nicol (1993) studied acoustic versus phonetic representation of speech represented by the MMN on a stimulus continuum varying in place of articulation from /da/ to /ga/. Two pairs of stimuli were chosen and presented in an oddball paradigm, one within category and one across phoneme boundaries. Since the MMN is considered an automatic response which does not require subject attention, the adults were instructed to watch a videotape during the recording of the evoked potentials. Results indicated that the MMN was detectable in all of the subjects in both the within and across categories condition. The repeated measures t-tests revealed that the MMN latency and amplitude measures were not significantly different in the within and across category conditions. That is, the MMN indicated equal discrimination both across and within categories. The authors conclude that the MMN appears to reflect the processing of acoustic aspects of the speech stimulus, but not the phonetic processing into categories. Also the MMN appears to be an extremely sensitive electrophysiologic index of minimal acoustic differences in speech stimuli.

Sams, Aulanko, Aaltonen, and Naatanen (1990) studied late evoked potentials to synthetic consonant-vowel syllables on a continuum of /bae/ through /dae/ to /gae/. The starting point of the F2 transition varied from 800 to 2800 Hz. The inter-stimulus interval was constant and equal to 510 ms. Standards were

presented with a 90% probability and deviants a 10% probability of occurrence. ERP's were recorded from 10 electrode sites, four in the zenith positions and three on each hemisphere. Potentials were recorded in ignore and attend conditions. Difference waveforms were constructed by subtracting the ERP's to the standards from those to the deviants. The authors concluded that the deviant phonetic stimuli, differing from the standards solely on the basis of the F2 starting frequency, elicit an MMN as well as an enhanced N100 deflection. In the ignore condition, the MMN and N100 showed no indication of categorical perception. The MMN was slightly larger over the right hemisphere than the left hemisphere. In the attend condition, some evidence for categorical perception was obtained in neural activity associated with later stages of auditory information processing reflected in P300 deflections. The P300 latency behaved more as if it was determined solely by physical separation between the stimuli, but the P300 amplitude seemed to be related to categorical processing. The P300 amplitude also showed a small but very systematic tendency toward larger amplitudes over the right hemisphere than the left.

Aaltonen, Niemi, Nyrke, and Tuhkanen (1987) investigated the event-related potentials in response to the endpoint of the Finnish vowels /i/ and /y/ paired with the intermediate boundary sound in an oddball paradigm. The adult

subjects were tested in an attend and ignore condition and the AEPs were recorded at the Fz (frontal zenith), Cz (central zenith), and the Pz (parietal zenith). Components of interest were the N2 in the attend and ignore condition and the P3 in the attend condition. The authors concluded that the N2 in the ignore condition was a pure index of the MMN and in the attend condition it reflected the cognitive N2 component, although they stated that the N2 at the Pz location could not be measured accurately in their study. Results revealed a main effect of electrode site with MMN larger at Fz than other sites and a significant interaction between electrode site and condition (attend/ignore). There was a main effect of phonetic condition, showing that the condition involving the pure vowels, or endpoints, produced larger MMN responses than the conditions involving the boundary stimuli. The attend/ignore main effect was not significant, although there was a significant interaction between electrode site and attend/ignore. There was a difference in N2 amplitude between the attend and ignore conditions at Fz but no difference at Cz. ANOVA on N2 latency measures revealed a significant main effect of phonetic condition with the pure vowels displaying shorter latencies than the vowel/boundary stimuli. Interestingly, the P3 data produced shorter latencies when /i/ was the deviant stimulus irrespective of whether the standard stimulus was the vowel /y/ or the boundary stimulus. The authors conclude that the

different response patterns between MMN and P3 suggest that some processing had taken place between these components.

In summary, electrophysiological measures provide information beyond the behavioral realm in the complex area of speech perception. Late auditory evoked potentials have been elicited from within and across phoneme boundaries and appear slightly larger in the right than left hemisphere. Molfese (1987) suggests three general findings that have emerged from his review of the literature on VOT: 1) perception of the VOT cue across phoneme boundaries appears to be controlled by several cortical processes, some restricted to the right-hemisphere site and some apparently common to both hemispheres, 2) there is a developmental pattern to the emergence of mechanisms related to VOT perception, and 3) the categorical effects do not appear to be restricted to language stimuli. In the Molfese studies discrimination within and across boundaries is inferred from variations in the brain waves produced by stimuli varying on a continuum in a task relevant mode. These stimuli are equiprobable and therefore the "rare or infrequent" condition producing a component is eliminated.

Speech acoustic processing has been reflected in the MMN (Aaltonen, Niemi, Nyrke, and Tuhkanen, 1987; Kraus, McGee, Sharma, Carrell, and Nicol, 1992; Sams, Aulanko, Aaltonen, and Naatanen, 1990; and Sharma, Kraus,

McGee, Carrell, and Nicol, 1993) and latency of the P3 (Sams et al., 1990). Cognitive perception or categorization of phonetic units has been reflected in the P3 amplitude (Sams et al., 1990). Studies of the MMN and P3 involved an "oddball paradigm" which infers discrimination within and across categories utilizing the "rare or infrequent" condition to observe if certain components exist. If the component exists then the brain perceived the stimulus as "rare" and must have discriminated it from the frequent one. Data has suggested continuous and categorical perception models that perhaps co-exist and could possible delineate acoustic and linguistic sensitivity.

RATIONALE

In order to understand speech, it is necessary to encode the continuous, variable sensory information and subsequently categorize the stimuli into meaningful units. Objective measures of auditory function can be obtained with acoustic reflex tests, otoacoustic emissions, and auditory brain stem responses. The MMN is a measure of central sensory function that may be used to measure the system's ability to discriminate acoustic contrasts essential for speech perception. The P300 component of the auditory evoked potential

has been associated with stimulus informational value and is therefore sensitive to the significance of the signal. Allophonic variations (within category) of a phoneme are not linguistically meaningful and are typically not perceived behaviorally. Neurophysiological data that could directly measure the organism's ability to discriminate and group acoustic information at the level of the cortex would enhance the understanding of central processing in the normal population. These measures may be helpful in explaining differences in speech perception among individuals with similar peripheral functioning (normal or with peripheral deficits). These procedures may also aid in understanding the neurophysiological pathways and mechanisms responsible for speech perception. With continued extensive research into the neurophysiological correlates of perception, it may be possible to locate the area/areas of breakdown in the disordered population to guide remediation techniques.

PURPOSE OF THE STUDY

The purpose of the study was to assess central sensory function and cognitive processing related to categorization of speech stimuli. Processing was studied using responses that occur at two different time periods after

stimulus onset and that are understood to be measures that reflect processing above the level of the brainstem: MMN(time range of 200+ ms) and P300 (time range of 300+ ms). This study is unique in looking at the MMN and P3 components to stimuli varying in voice onset time, as well as the simultaneous recording of both components during an "ignore" task and the number of responses averaged to acquire data.

EXPERIMENTAL QUESTIONS

1) Is the MMN elicited by within and/or across categories of /ba/ and /pa/?

2) Is the P3 elicited by within and/or across categories of /ba/ and /pa/?

3) Is there a difference in the MMN among the phonetic conditions?

4) Is there a difference in the P3 among the phonetic conditions?

CHAPTER II

METHODS

STIMULI

The syllables /pa/ and /ba/ were spoken by a male speaker, recorded, digitized, and stored to a Macintosh computer. Observations and measurements were made on time waveforms of the syllables produced by the Sound Edit Pro software. Onset and offset of the syllable could be adjusted by changing time cursors on the waveform display and the modified syllable could be presented acoustically. The within category /ba/ stimuli were created by including in the stimulus window 30 ms prevoicing (30 ms of voicing prior to the burst) and the alternate /ba/ syllable with 0 ms VOT (voicing immediately after the burst). The within category /pa/ stimuli were created by including in the stimulus window 30 ms VOT delay (30 ms delay in onset of voicing after the burst) and its alternate signal with 60 ms VOT delay (60 ms delay in onset of voicing after the burst. See Figure 2 for stimulus waveforms. The /ba/ with 0 ms VOT and the /pa/ with 30 ms VOT delay were used for the across

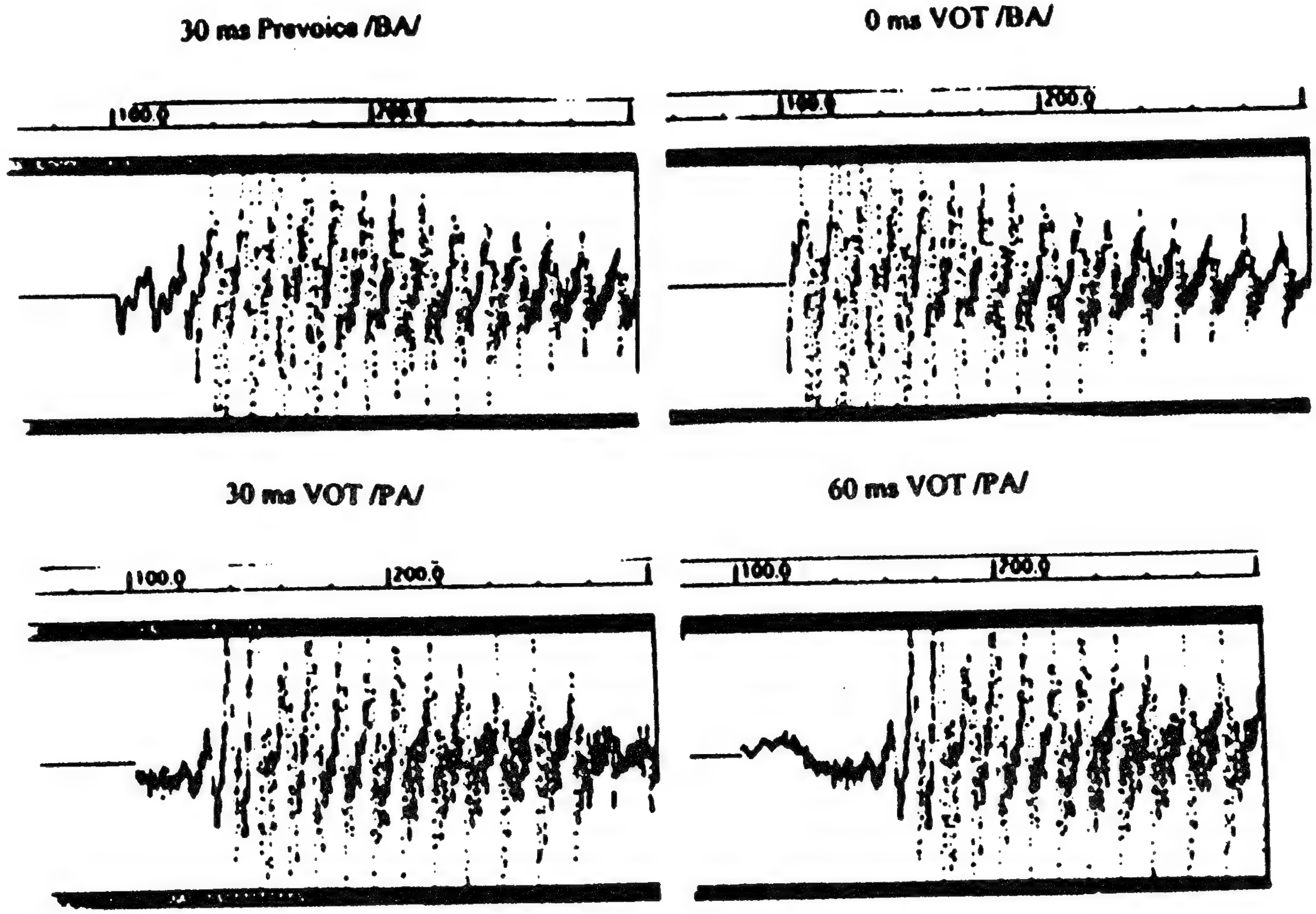


Figure 2. Stimulus Waveforms

category stimuli. The stimulus duration for each of the four stimuli was held constant at 200 ms.

BEHAVIORAL EXPERIMENT TO VALIDATE LINGUISTIC CHARACTERISTICS OF STIMULI

1. Subjects: Ten adult subjects, male and female, mean age 25 years (range: 22 to 33) participated in the study. All the subjects were native English speakers, had hearing thresholds of 20 dB HL or less for pure tones at 500, 1000, 2000, and 4000 Hz in both ears, and had no known neurological, cognitive, or learning deficits as reported by subjects.

2. Procedure: In the labeling task, each of the four stimuli were presented in randomized order in each of 10 trials. The subjects were asked to identify each stimulus as belonging to one of the two categories (/ba/ or /pa/), indicating the judgement on a forced choice response sheet. In the ABX discrimination task, each stimulus pair was presented in all four possible orders of ABA, ABB, BAB, and BAA randomly two times each. The subjects task was to listen to the first two stimuli and indicate whether the third stimulus

sounded more like the first or more like the second by circling either 1 or 2 on a response form.

3. Results: Labeling functions were averaged over responses of the ten subjects and are shown in Figure 3. Distinct labeling categories with 30 ms prevoicing and 0 ms VOT were identified as /ba/ and 30 ms VOT delay and 60 ms VOT delay identified as /pa/. Results of the ABX discrimination task, shown in Figure 4, indicated chance performance (58 percent) in discrimination of stimuli drawn from the same labeling category (within category) /pa/ and slightly better discrimination of stimuli drawn from within category /ba/ (71 percent). Stimuli drawn from across category /ba/ to /pa/ were discriminated with 100 percent accuracy.

5. Conclusion: The stimuli used in the present study were natural speech utterances that were digitized and modified temporally. The behavioral data indicate that the stimuli have the desired perceptual characteristics: they are easily discriminated across categorical boundaries and are confused within categories.

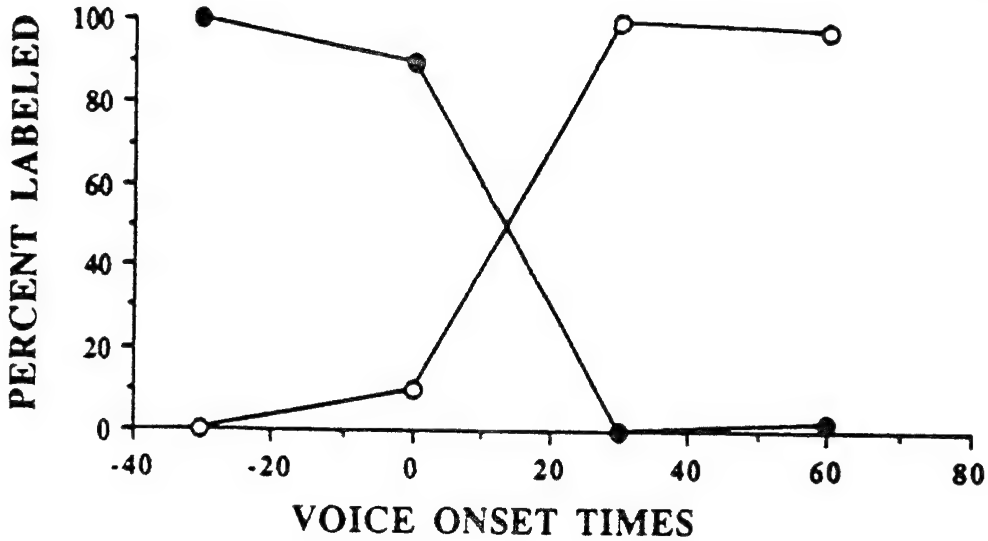


Figure 3. Results of labeling task averaged over ten subjects

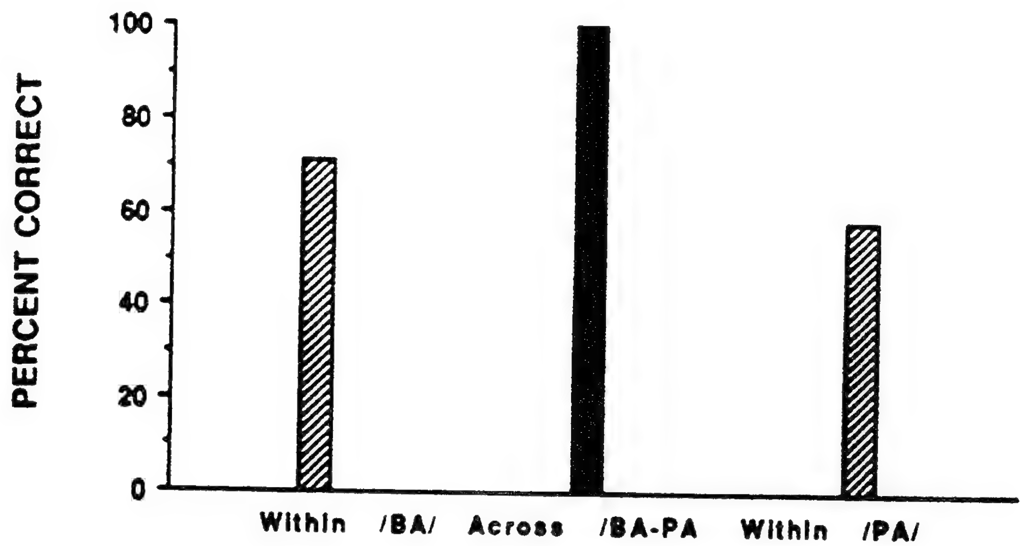


Figure 4. Results of ABX discrimination task averaged over ten subjects

ERP EXPERIMENT

1. Stimuli: The same speech stimuli pairs were utilized from the labeling and ABX discrimination tasks with the addition of one pair consisting of the endpoints. The stimuli were generated with four pairs of stimuli chosen for the ERP experiment as follows: two within category pairs and two across category pairs. 1) The 30 ms prevoicing and the 0 ms VOT were identified as within the same category /ba/; 2) the 30 and 60 ms VOT stimuli were identified as within the same category /pa/; 3) the 0 ms and 30 ms VOT pair was chosen to represent across or different categories, /ba/ and /pa/ respectively, so that three pairs of stimuli differed by 30 ms; and 4) the endpoint across category pair consisted of the -30 ms VOT /ba/ and 60 ms VOT /pa/ differing in VOT by 90 ms. (see descriptions below) Interstimulus interval was held constant at 1300 ms.

The four trial blocks:

1) 30 ms prevoicing and 0 ms VOT	=	within /ba/ category
2) 30 ms VOT and 60 ms VOT	=	within /pa/ category
3) 0 ms VOT and 30 ms VOT	=	across /ba to pa/ category
4) 30 ms prevoicing and 60 ms VOT	=	across endpoints category

Evoked responses to 80 deviant and 320 frequent stimuli made up a condition trial block. Four hundred stimuli is the upper limit of the number of stimuli the EPACS software can average. Most studies on the MMN are made in an ignore condition and usually average approximately 1000 stimuli. Studies on the P3 are usually in an attend condition with as few as 100 stimuli. (See review of attentional affects on evoked potentials.) Order of presentation of the four stimulus trial blocks were systematically altered in sequence (e.g. 1,2,3,4; 2,3,4,1; 3,4,1,2; and 4,1,2,3) so as to alleviate an order or fatigue effect.

2. Subjects: 27 adult volunteers between the ages of 18 and 35 years participated in the study. Qualifying criteria included; hearing thresholds of 20 dB HL or less for pure tones at 500, 1000, 2000, and 4000 Hz in both ears;; and no known neurological, cognitive, or learning deficits (verbal confirmation by subject)

3. Methods and Procedures: An "oddball paradigm" was used in each pair with a deviant probability of occurrence 20%. In the within category /ba/ and across category /ba/ to /pa/ the 0 ms VOT stimulus was used as the deviant. The 60 ms VOT stimuli was the deviant in the within /pa/ and in the endpoint pair. The selection of the deviant stimuli was arbitrary but the use of the same

stimuli as the deviant in the within and across category pairs was used in an effort to control ERP differences due to the physical stimuli rather than the condition.

ERP's were recorded from 6 mm cup disk surface electrodes with protected leads (F-E5 GH) placed on the scalp at the frontal zenith (Fz), central zenith (Cz), parietal zenith (Pz), and left/right parietal (P3/P4) locations according to the International 10-20 system, with linked reference electrodes on both ears and a forehead ground. Acceptable impedance measures were 5K ohms or less for each electrode and no more than a 5K ohm difference between any two electrodes.

The recording window included a 100 ms prestimulus period and 700 ms of post-stimulus onset time. Stimuli were presented via overhead speaker at 70 dB A-scale fast response at ear level as measured by a Realistic sound level meter. The subjects' task was to sit in a comfortable position, hold physical movements to a minimum, and read silently to help control attentional effects and muscle artifact. Each trial block took approximately ten minutes and the subject was allowed to rest between trial blocks. The electrodes were attached to Isolation/Amplifiers (Grass units P511k) with their own power supply (Grass RPS107). Frequency range settings were from .1 to 30 Hz.

Mounted oscilloscopes were used for visual monitoring of the responses. The amplified analog responses were passed through an additional low pass (45Hz) filter and then through an analog-to-digital benchtop converter (Metaresearch). The digital responses were stored and analyzed in a Macintosh SE microcomputer. Automatic artifact rejection was performed when peak response amplitude exceeded $\pm$ 45 uV. The EPACS software averaged the responses to the deviant and frequent stimuli in each condition. Following the test procedure, the electrode impedances were checked again.

4. Component identification and measurement: Component identification and measurement was performed on the Cz location selected on the basis of finding from pilot study data.

a. Averaged waveforms for the deviant and frequent stimuli in each of the four phonetic conditions were visually inspected for the MMN and P3 components. Operational definition of the MMN was a relative negativity following the P2 (which was apparent in the standard and deviant waveforms) in the latency range of 200+ ms. Operational definition of the P3 was the greatest relative positivity in the latency of approximately 300 ms.

b. There is no agreed upon standard method of measuring the amplitude of ERP components (Hall, 1992). All measures were based on a

Baseline to Peak (BTP). To obtain the BTP the difference was taken between the voltage at a point of interest on the waveform and the average voltage for 100 ms before stimulus onset. Two measures were made in the present study: 1) Greatest peak. The difference was taken between the voltage of the BTP measure at the greatest peak of the deviant vaveform and the BTP at the greatest peak of the frequent waveform, and 2) Point to Point.

The difference was taken between the voltage of the BTP measure at the greatest peak of the deviant and frequent waveforms at the point at which the deviant waveform was greatest. (see Figure 5) These two procedures were done also in an effort to control differences that might exist in the ERPs due to physical differences in the stimuli rather than differences due to condition.

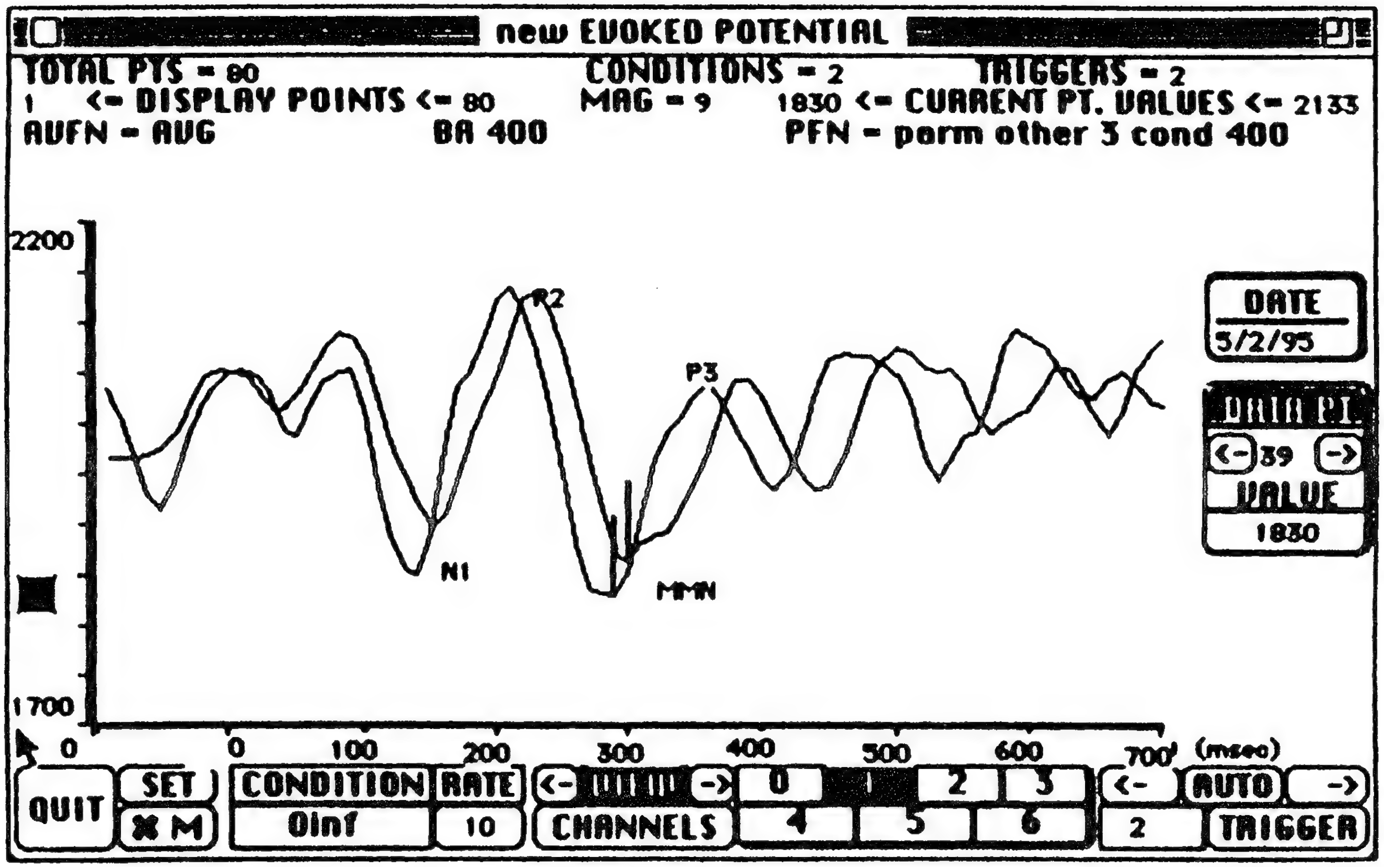


Figure 5. Overlay of frequent and deviant waveforms collected in a within /ba/ condition. Cursors represent points of greatest negativity of the MMN.

CHAPTER III

RESULTS

PRESENCE OF MMN AND P3

The results for the four experimental conditions were analyzed to determine if the MMN and P3 were present for each condition. The measure computed was the difference in voltage amplitude (uv) from baseline between responses to frequent and deviant stimuli. Analysis with the Shapiro - Wilk Statistic revealed that at least one of the sets of data was not normally distributed. As a result, the data were analyzed using a nonparametric test - the Wilcoxon Matched Pairs Sign Test. The .02 level of confidence was used at the criterion for significance. This level was chosen due to the number of tests performed and possible erosion of the alpha level. The differences were significant between frequent and deviant stimuli (see Tables 1 and 2) indicating the presence of significant MMN and P3 responses for each of the experimental conditions. These findings indicate that neural processing is

Table 1. Results of the Wilcoxon Matched Pairs Sign Test for the MMN. Probability based on amplitude of the Infrequent minus Frequent and direction of difference in each condition.

CONDITION	PROBABILITY
1) WITHIN /BA/	p=.0001
2) WITHIN /PA/	p=.0000
3) ACROSS /BA TO PA/	p=.0000
4) ACROSS EXTREME	p=.0001

Table 2. Results of the Wilcoxon Matched Pairs Sign Test for the P3. Probability based on amplitude of the Infrequent minus Frequent and direction of difference in each condition.

CONDITION	PROBABILITY
1) WITHIN /BA/	p=.0000
2) WITHIN /PA/	p=.0007
3) ACROSS /BA TO PA/	p=.0000
4) ACROSS EXTREME	p=.0000

different for frequent and infrequent stimuli in the time of both the MMN and P3 within and across phonetic categories.

AMPLITUDE AND LATENCY DIFFERENCES OF MMN AND P3

The mean amplitudes of MMNs for the four experimental conditions are shown in Figure 6 for the point-to-point amplitude measure and in Figure 7 for the greatest peak measure. The results were similar for the two measures: the amplitudes for three of the four conditions (within /ba/, /ba-pa/, and extreme) is slightly greater than for the within /pa/ condition. For each measure pairwise comparisons were made between the within /pa/ and the other three conditions using the Wilcoxon Matched Pairs Sign Test. None of the six differences were significant. These results indicate that the amplitudes of MMNs are not altered significantly by the phonemic parameters manipulated in this study.

The mean latencies of the MMNs of the deviant stimuli in the four phonetic conditions are shown in Figure 8. The latency of the within /pa/ condition is slightly longer than the latency for the other three conditions but

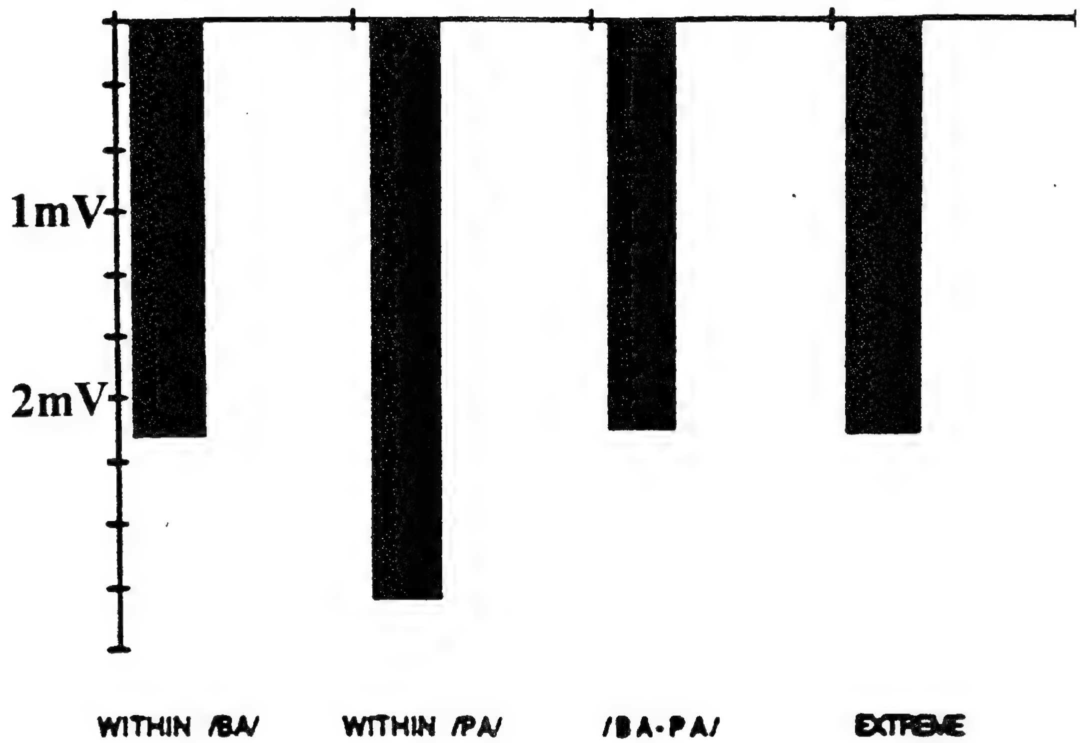


Figure 6. Mean amplitudes of the MMN as a function of the difference between the average frequent and average deviant point to point measures in the four phonetic conditions

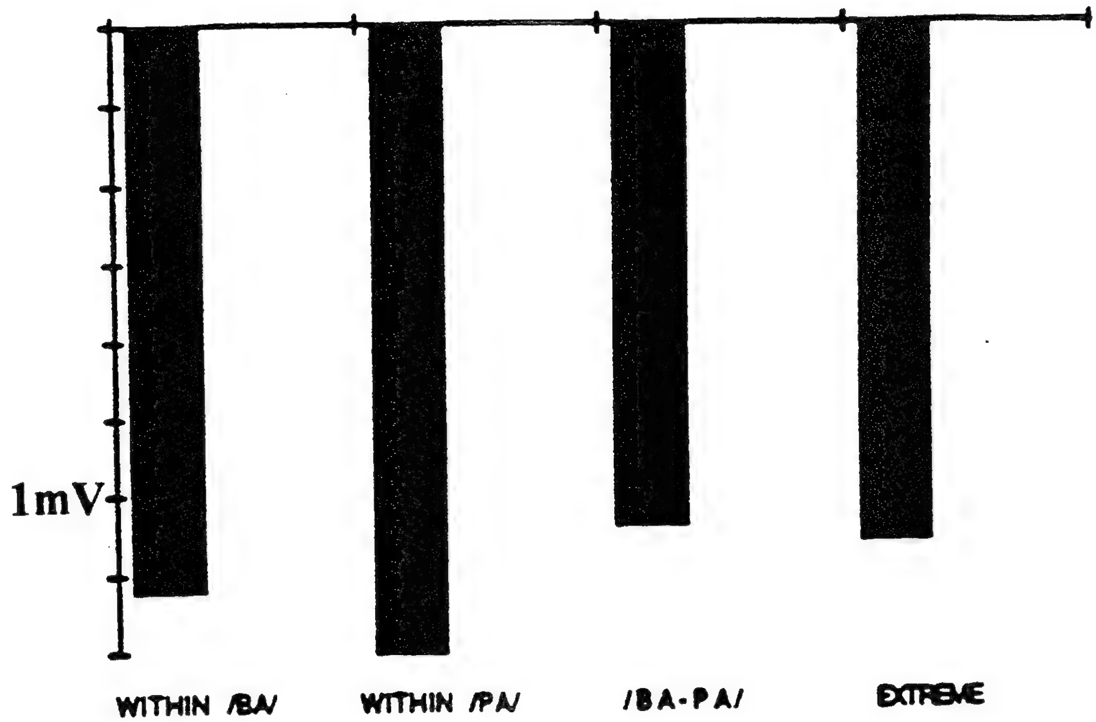


Figure 7. Mean amplitudes of the MMN as a function of the difference between the aberage frequent and average deviant greatest peak measures in the four conditions

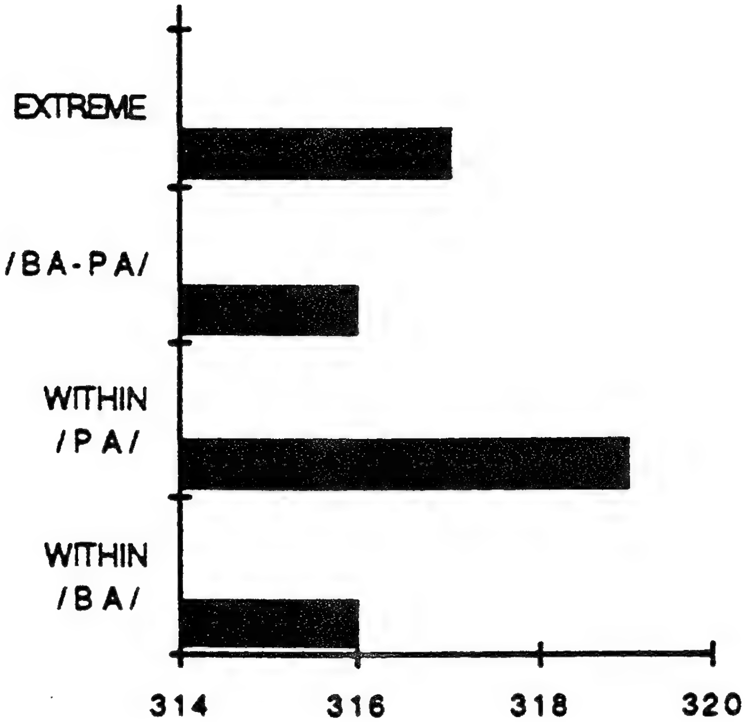


Figure 8. Mean latencies of the MMN of the infrequent stimuli in the four phonetic conditions

pairwise comparisons using the Wilcoxon Matched Pairs Sign Test indicated that the differences were not significant.

The mean amplitudes of the P3s for the four experimental conditions are shown in Figure 9 for the point to point amplitude measure and in Figure 10 for the greatest peak measure. These results are also very similar for the two measures. The Wilcoxon Matched Pairs Sign Test demonstrated that the across categories were significantly greater than the within categories in the point to point and the greatest peak analysis. See Tables 3 and 4 for pairwise results. The pairwise comparisons indicated the results in the /ba-pa/ condition were greater than in the within /pa/ condition in both analysis. Additionally in the greatest peak analysis the /ba-pa/ was also greater than the within /ba/. These results indicate that the amplitudes of the P3 are altered significantly by the phonemic parameters manipulated in this study.

Mean latencies of the P3 in the deviant condition in the four conditions are plotted in Figure 11. The latency of the P3 in the /ba-pa/ condition was slightly longer than the other three conditions but the results of the pairwise comparisons using the Wilcoxon Matched Pairs Sign Test indicated no significant differences among the conditions of within and across categories.

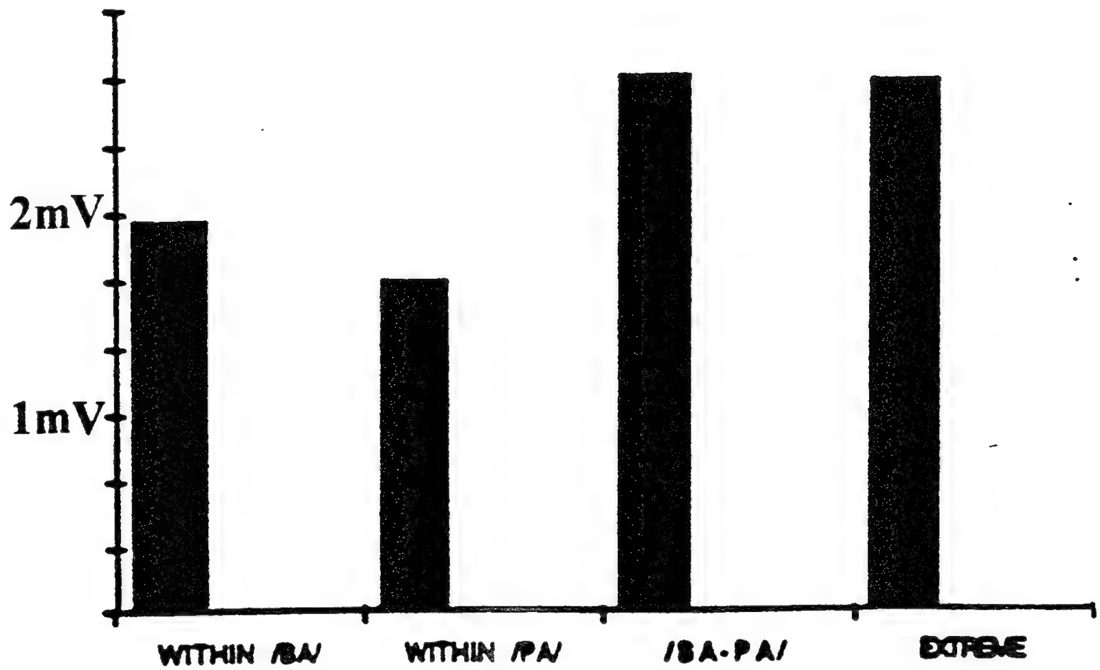


Figure 9. Mean amplitudes of the P3 as a function of the difference between the average frequent and average deviant point to point measures in the four phonetic conditions

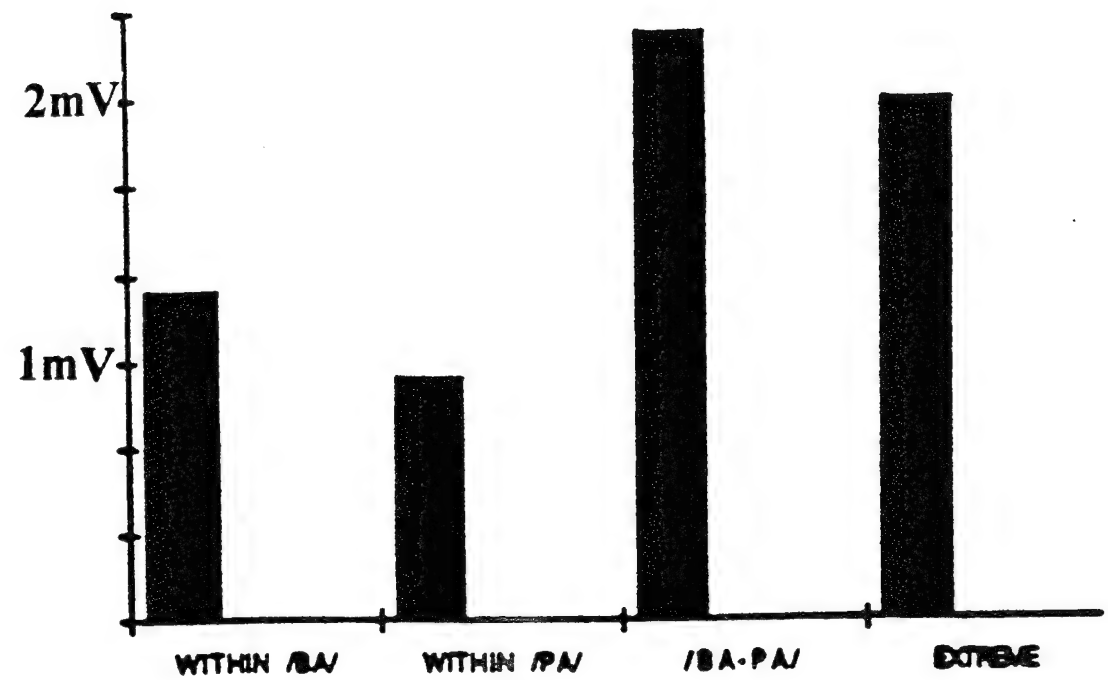


Figure 10. Mean amplitudes of the P3 as a function of the difference between the average frequent and average deviant greatest peak measures in the four conditions

Table 3 Results of Wilcoxon Matched Pairs Sign Test for all pairwise comparisions of conditions. Probabilities are based on difference in amplitudes of Infrequent and Frequent Point to Point Measures.

CONDITION BY CONDITION	1) WITHIN /BA/	2) WITHIN /PA/	3) ACROSS /BA TO PA/	4) ACROSS EXTREME
1) WITHIN /BA/		1>2 p=.80	1<3 p=.11	1<4 p=.19
2) WITHIN /PA/			2<3 p=.02	2<4 p=.10
3) ACROSS /BA TO PA/				3>4 p=.64
4) ACROSS EXTREME				

Table 4. Results of Wilcoxon Matched Pairs Sign Test for all pairwise Comparisons of conditions. Probabilities are based on difference in amplitudes of Infrequent and Frequent Greatest Peak Measures.

CONDITION BY CONDITION	1) WITHIN /BA/	2) WITHIN /PA/	3) ACROSS /BA TO PA/	4) ACROSS EXTREME
1) WITHIN /BA/		1>2 p=.47	1<3 p=.01	1<4 p=.29
2) WITHIN /PA/			2<3 p=.01	2<4 p=.07
3) ACROSS /BA TO PA/				3>4 p=.43
4) ACROSS EXTREME				

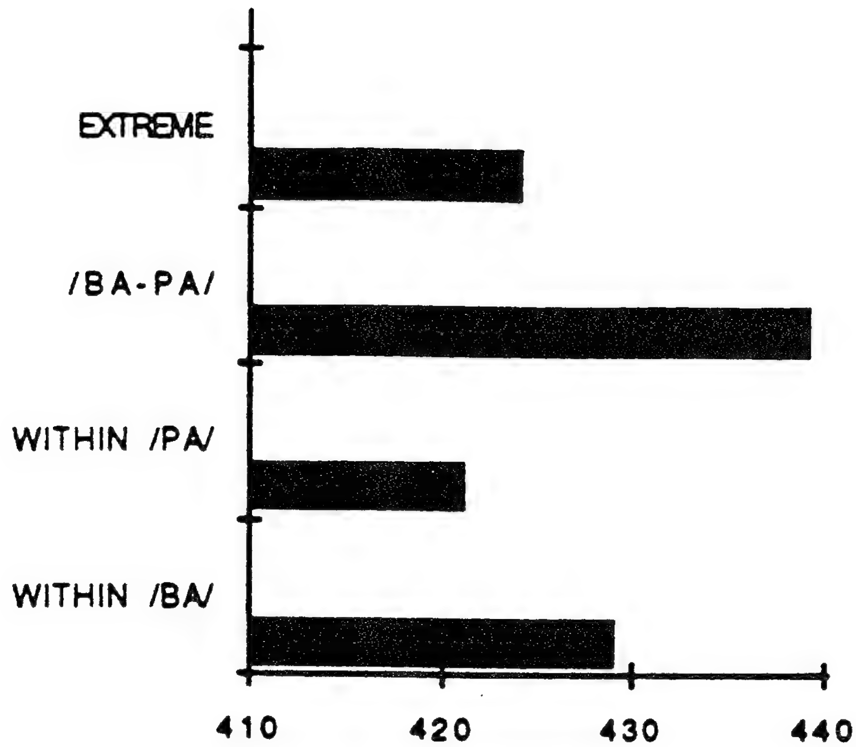


Figure 11. Mean latencies of the P3 of the infrequent stimuli in the four phonetic conditions

In summary, the MMN and P3 components of the auditory evoked potential were identified in the within and across categories of voice onset time. P3 amplitude depended on phonemic category; MMN amplitude did not.

CHAPTER IV

DISCUSSION

The presence of MMNs and P3s for all conditions provides evidence that auditory discriminations were made for all the pairs of stimuli tested. Furthermore these discriminations were made in the time period of the MMN which has been associated with auditory discrimination and in the time period for the P3 which is associated with "more linguistic processing". It indicates that even though linguistic processing is occurring in which acoustically different signals are being grouped into allophonic categories, the discriminatory information is not being thrown away as suggested by Handel.

What does occur in the time domain of P3, is that information on categorization is added in a manner that can be seen as a difference in the amplitude of P3s for stimuli within and across categorical boundaries. The major finding of this study is that information about the categorization of linguistic stimuli is encoded in the amplitude of P3 and not in the latency of the response. Further, the failure to find significant amplitude and latency differences within and across phonetic categories in the MMN responses

suggests that linguistic processing may not occur in the temporal domain of the MMN and may first occur in the temporal domain of the P3

The P3 amplitude is related to categorical processing in the present study. Sams et al. (1990) found that an increase in acoustical difference (frequency) did not increase the P300 amplitude unless the increase also signified that the deviant stimulus moved out of the category of the standard stimulus. Maiste et al. (1995) showed that the categorical perception of stimuli from the /ba/ - /da/ continuum is associated with the N2-P3 measurement of the ERP. The present study collected P3 data in an ignore task simultaneous with the MMN in contrast to other studies which derived P3 data from an attend condition. Some authors categorize this component as a P3a which notes an acoustic change similar to the MMN (Picton, 1995) although analysis revealed phonemic categorization at this level in the present study.

No significant differences were found in the P3 latency measures among the conditions. Sams et al. (1990) found P3 latencies to behave more as if they were determined solely by physical separation between the stimuli. The greater acoustic difference between the standard and the deviant stimuli, the shorter the latencies. It should be noted that in the Sams et al. study twelve incremental frequency differences across three syllables were used with a

greater extreme comparison. Aaltonen et al. (1987) found that the pure vowel /i/ as the deviant produced a P3 component of a short latency irrespective of whether the standard stimulus was the pure Finnish vowel /y/ or the phoneme boundary. Physical acoustic differences were controlled in the present study with the exception of the extreme condition. Although no significant differences were found in the P3 latencies, it can be noted that the 60 ms /pa/ as the deviant produced the shortest latencies.

The present study was consistent with Sharma et al. (1993) finding no significant differences in the MMN amplitudes or latencies within and across category conditions. Maiste et al. (1995), as stated above, found varying amplitudes according to latency range of the MMN. In contrast Aaltonen et al. (1987) found shorter latencies of N2 (ignore condition) for Finnish pure vowel pairs rather than pure-border conditions. It should be noted that the present study examined evoked potentials to differences in voice onset time and the studies used for comparison had stimuli that differed in frequency of F2. Kraus et al. (1995) points out that complex speech stimuli may not produce similar MMN characteristics.

In conclusion this study supports the MMN as a neurophysiological measure of acoustic discrimination and the P3 as a later cognitive

categorization. Further the MMN was elicited by as few as 400 stimuli in the ignore condition and both the MMN and P3 were elicited simultaneously. This finding suggests a practical value in measuring acoustic sensitivity in a clinical population.

REFERENCES

Aaltonen, O., Niemi, P., Nyrke, T. and Tuhkanen, M. (1987). Event Related Brian Potentials and the Perception of a Phonetic Continuum. Biological Psychology, 24, 197-207.

Adler, G., and Adler, J. (1991). Auditory stimulus processing at different stimulus intensities as reflected by auditory evoked potentials. Biological Psychology, 29, 347-56.

Ahonniska, J., Cantell, M., Tolvanen, A., and Lyytinen, H. (1993). Speech perception and brain laterality: The effect of ear advantage on auditory event-related potentials. Brain and Language, 45, 127-146.

Alho, K., Huotilainen, M., Tiitinen, H., Limoniemiu, R., Knuutila, J., and Naatanen, R. (1993). Memory- related processing of complex sound patterns in human auditory cortex: a MEG study. NeuroReport, 4, 391-394.

Alho, K., Sams, M., Paavilainen, P., Reinikainen, K, and Naatanen, R. (1989). Event-related brain potentials reflecting processing of relevant and irrelevant stimuli during selective listening. Psychophysiology, 26, 514-528.

Barclay, J.R. (1972). Noncategorical perception of a voiced stop: A replication. Perception and Psychophysics, 11, 269-273.

Carney, A.E., Widen, G.P, and Viemeister, N.F. (1977). Noncategorical perception of stop consonants differing in VOT. Journal of the Acoustical Society of America, 62, 961-970.

Chapman, R.M., McCrary, J.W., Bragdon, H.R., and Chapman, J.A. (1979). Latent Components of Event-Related Potentials Functionally Related to Information Processing. In J.E. Desmedt (Ed.), Cognitive Components in Cerebral Event-Related Potentials and Selective Attention. Switzerland: S. Karger Ag.

Courchesne, E. (1978). Neurophysiological Correlates Of Cognitive Development: Changes In Long-Latency Event-Related Potentials From Childhood To Adulthood. Electroencephalography and Clinical Neurophysiology., 45, 468-482.

Courchesne, E., Hillyard, S., and Galambos, R. (1975). Stimulus novelty, task relevance and the visual evoked potential in man. Electroencephalography and Clinical Neurophysiology, 39, 131-143.

Donchin, E. (1978). Cognitive Psychophysiology. In Callaway, Tueting, and Koslow (Ed.), Event-Related Brain Potentials In Man. New York: Academic Press.

Donchin, E. (1981). Surprise!...Surprise? Psychophysiology, 18, 493-513.

Donchin, E. (1984). Dissociation Between Electrophysiology and Behavior-A Disaster or a Challenge? In E. Donchin (Ed.), Cognitive Psychophysiology. New Jersey: Lawrence Erlbaum Associates, Inc.

Duncan-Johnson, C., and Donchin, E. (1977). On quantifying surprise: The variation of event-related potentials with subject probability. Psychophysiology, 14, 456-467.

Eimas, P.D., Miller, J.L., and Juszyk, P.W. (1987). On infant speech perception and the acquisition of language. In S. Harnad (Ed.) Categorical Perception (pp. 161-195). Cambridge: University Press.

Fischler, I.S. (1990). Comprehending Language With Event-Related Potentials. In Rohrbaugh, Parasuraman, Johnson (Ed.), Event-Related Brain Potentials Basic Issues and Applications. Oxford University Press, Inc.

Ford, J., Roth, W., and Kopell, B. (1976). Attention effects on auditory evoked potentials to infrequent events. Biological Psychology, 4, 65-7.

Hall, J. (1992). Waveform Analysis. In J. Hall (ed.), Handbook Of Auditory Evoked Responses (pp. 221-263). Needham Heights: Allyn and Bacon.

Handel, Stephen (1991). Phonemes: Notes and Intervals. In S. Handel (ed.), Listening: An Introduction to the Perception of Auditory Events (pp.265-319). Cambridge: The MIT Press.

Hari, R., Hamalainen, M., Ilmoniemi, R., Kaukoranta, E., Reinikainen, K., Salminen, J., Alho, K., Naatanen, R., and Sams, M. (1984). Responses of the primary auditory cortex to pitch changes of tone pips: Neuromagnetic recordings in man. Neuroscience Letters, 50, 127-132.

Harnad, Stevan (1987). Introduction: Psychophysical and cognitive aspects of categorical perception: A critical overview. In S. Harnad (Ed.), Categorical Perception, (pp. 1-25). Cambridge: University Press.

Hillyard, S., Squires, K., Bauer, J., and Lindsay, P. (1971). Evoked potential correlates of auditory signal detection. Science, 172, 1357-1360.

Hoffman, J. E. (1990). Event-Related Potentials and Automatic and Controlled Processes. In Rohrbaugh, Parasuraman, and Johnson (ed.), Event-Related Brain Potentials Basic Issues and Applications. Oxford: University Press.

Ivy, R.G. and Schmidt, H.B. (1993). P300 Response: Habituation. Journal of American Academy of Audiology. 4, 182-188.

Jasper, H.H. (1958). Report of the committee on methods of clinical examination in electroencephalography. The ten-twenty electrode system. Electroencephalography and clinical Neurophysiology., 10, 371-375.

Johnson, R. (1988). The amplitude of the P300 component of the event-related potential: Review and synthesis. In P.K. Ackles, J.H. Jennings, and M.G. Coles (Eds.), Advances in Psychophysiology, Vol. III (pp. 69-137). Greenwich, Conn: JAI Press.

Kaukoranta, E., Sams, M., Hari, R., Hamalainen, M., and Naatanen, R. (1989). Reaction of human auditory cortex to changes in tone duration. Hearing Research, 41, 15-22.

Kewley-Port, D., Watson, C.S., and Foyle, D.C. (1988). Auditory temporal acuity in relation to category boundaries; speech and nonspeech stimuli. J. Acoust. Soc. Am, 83, 1133-1145.

Kraus, N., Mcgee, T., Sharma, M., Carrell, and Nicol, T. (1992). Mismatch Negativity Event-Related Potential Elicited by Speech Stimuli. Ear and Hearing, 13, 158-164.

Ladish, C. and Polich, J. (1989). P300 and probability in children. Journal of Experimental Child Psychology, 48, 212-223.

Liberman, A.M., Cooper, F.S., Shankweiler, D., and Studdert Kennedy, M. (1967). Perception of the speech code. Psychological Review, 74, 431-461.

Liberman, A.M., Harris, K.S., Hoffman, H.S., and Griffith, B.C. (1957). The discrimination of speech sounds within and across phoneme boundaries. Journal of Experimental Psychology, 54, 358-368.

Lisker, L. and Abramson, A.S. (1964). Cross-Language study of voicing in initial stops: acoustical measurements, Word, 20, 384-422.

Macmillan, N.A. (1987). Beyond the categorical/continuous distinction: A psychophysical approach to processing modes. In S. Harnard (ed.), Categorical Perception (pp. 53-85). Cambridge: University Press.

Macmillan, N.A., Kaplan, H.L., and Creelman, C.D. (1977). The Psychophysics of categorical perception. Psychological Review, 84, 452-471.

Maiste, A., Wiens, A., Hunt, M., Scherg, M., and Picton, T. (1995). Event-Related Potentials and the Categorical Perception of Speech Sounds. Ear and Hearing, 16, 68-90.

Mantysalo, S. and Naatanen, R. (1987). The duration of a neuronal trace of an auditory stimulus as indicated by event-related potentials. Biological Psychology, 24, 183-195.

McCarthy, G., and Donchin, E. (1981). A metric for thought: A comparison of P300 latency and reaction time. Science, 211, 77-80.

Miller, J.D., Wier, C.C., Pastore, R.E., Kelly, W.J., and Dooling, R.J. (1976). Discrimination and labeling of noise buzz sequences of categorical perception. Journal of the Acoustical Society of America, 60, 410-417.

Molfese, D. L. (1978). Neuroelectrical Correlates of Categorical Speech Perception in Adults. Brain and Language, 5, 25-35.

Molfese, D.L. (1987). Electrophysiological indices of categorical perception for speech. In S. Harnard (Ed.), Categorical Perception (pp. 421-444). Cambridge: University Press.

Molfese, D.L., and Hess, T. (1978). Hemispheric specialization for VOT perception in the preschool child. Journal of Experimental Child Psychology, 26, 71-84.

Molfese, D.L., and Molfese, V.J. (1985). Electrophysiological indices of auditory discrimination in newborn infants: The bases for predicting later language development? Infant Behavior and Development, 8, 197-211.

Musiek, F.E., Verkest, S.B., and Gollegly, K.M. (1988). Effects of neuromaturation on auditory evoked potentials. Seminars in Hearing, 9, 1-13.

Naatanen, R. (1982). Processing Negativity: An evoked-potential reflection of selective attention. Psychological Bulletin, 92, 605-640.

Naatanen, R. (1985). Stimulus processing: Reflections in event-related potentials, Magnetoencephalogram, and regional cerebral blood flow. In M.I. Posner and O.S.M. Marin (Eds.), Mechanisms of attention: Attention and Performance, Vol.XI. (pp. 355-373). Hillsdale, J.J.: Erlbaum.

Naatanen, R. (1990). The role of attention in auditory information processing as indicated by event-related potentials and other measures of cognitive function. Behavioral and Brain Research, 13, 119-127.

Naatanen, R. (1995). The Mismatch Negativity: A Powerful Tool for Cognitive Neuroscience. Ear and Hearing, 16 (1), 6-18.

Naatanen, R., and Gaillard, A. (1983). The orienting reflex and the N2 deflection of the ERP. In A.W.K. Gaillard and W. Ritter (Eds.), Tutorials in event-related potential research: Endogenous components (pp. 119-141). Amsterdan: Elsevier.

Naatanen, R., Gaillard, A., and Mantysalo, S. (1978). Early selective attention effect reinterpreted. Acta Psychologia, 42, 313-329.

Naatanen, R., Paavilainen, P., Alho, K., Reinkainen, K., and Sams, M. (1989). Do event-related potentials reveal the mechanism of the auditory sensory memory in the human brain? Neuroscience Letters, 98, 217-21.

Naatanen, R., Paavilainen, P., and Reinikainen, K. (1989). Do event-related potentials to infrequent decrements in auditory stimuli demonstrate a memory trace in man? Neuroscience Letters, 107, 347-352.

Naatanen, R., Schroger, E., Karakas, S., Tervaniemi, M., and Paavilainen, P. (1993). Development of a memory trace for a complex sound in the human brain. Neuroreport, 4(5), 503-506.

Paavilainen, P., Jiang, D., Lavikainen, J., and Naatanen, R. (1990). Stimulus duration and the sensory memory trace: An event-related potential study. Electroencephalography and Clinical Neurophysiology, 69, 139-151.

Picton, Terrence W. (1995). The Neurophysiological Evaluation of Auditory Discrimination. Ear and Hearing, 16, 1-5.

Pisoni, D.B. (1977). Identification and discrimination of the relative onset time of two component tones: Implications for voicing perception in stops. Journal of Acoustical Society of America, 61, 1352-1361.

Polich, J. (1986a). Attention, probability, and task demands as determinants of p300 latency from auditory stimuli. Electroencephalography and Clinical Neurophysiology, 63, 251-259.

Polich, J. (1986b). Normal variation of P300 from auditory stimuli. Electroencephalograpy and Clinical Neurophysiology., 63. 236-240.

Polich, J. (1989). Frequency, intensity, and duration as determinants of P300 from auditory stimuli. Journal of Clinical Neurophysiology, 6(3), 277-86.

Pritchard, W. (1981). The psychophysiology of P300. Psychological Bulletin, 89, 506-540.

Rappaport, M., Clifford, J., and Winterfield, K. (1990). P300 response under active and passive attentional states and uni-and bimodality stimulus presentation conditions. Journal of Neuropsychiatry and Clinical Neurosciences, 2, 399-407.

Repp, B.H. (1984). Categorical Perception: Issues, Methods, Findings. In N.J. Lass (Ed.), Speech and Language: Advances in Basic Research and Practice, (Vol. 10). New York: Academic Press.

Reuter, B.M. and Linke, D.B. (1989). P300 and Coma. In K. Maurer (ed.), Topographic Brain Mapping of EEG and Evoked Potentials (pp. 192-196). Berlin Heidelberg: Springer-Verlag.

Ritter, W., Simpson, R., and Vaughan, H.G. (1983). Event related potentials and two sequential stages of information processing in physical and semantic discrimination. Psychophysiology, 20, 168-169.

Rockstroh, B., Elbert, T., Birbaumer, N., and Lutzenberger, W. (1982). Event-Related Potentials. In Rockstoh, Elbert, Birbaumer, and Lutzenberger (ed.), Slow Brain Potentials and Behavior (pp. 1-38). Baltimore: Urban & Schwarzenberg.

Sams, M., Aulanko, R., Aaltonen, O., and Naatanen, R. (1990). Event-related potentials to infrequent changes in synthesized phonetic stimuli. Journal of Cognitive Neuroscience, 2, 344-357.

Schroger, E., Naatanen, R., and Paavilainen, P. (1992). Event-related potentials reveal how non-attended complex sound patterns are represented by the human brain. Neuroscience Letters, 146, 183-186.

Sharma, A., Kraus, N., Mcgee, T., Carrell, T., and Nicol, T. (1993). Acoustic versus phonetic representation of speech as reflected by the mismatch negativity event-related potential. Electroencephalography and Clinical Neurophysiology, 88, 64-71.

Sklare, D.A. and Lynn, G.E. (1984). Latency of the P3 event-related potential: normative aspects and within-subject variability. Electroencephalography and Clinical Neurophysiology., 59, 421-424.

Simon, C., and Fourcin, A.J. (1978). Cross-Language study of speech-pattern learning. Journal of the Acoustical Societyof America, 63, 925-935.

Sokolov, E.N. (1975). The neuronal mechanisms of the orienting reflex. In E.N. Sokolov (ed.) Neuronal mechanisms of the orienting reflex. Hillsdale, N.J. Erlbaum Ass.

Squires, K., Donchin, E., Herning, R., and McCarthy, G. (1977). On the influence of task relevance and stimulus probability on event-related potential components. Electroencephalography and and Clinical Neurophysiology, 42, 1-14.

Squires, K., Hillyard, S., and Lindsay, P.(1973). Vertex potentials evoked during auditory signal detection: Relation to decision criteria. Perception and Psychophysics, 10, 445-457.

Squires, N.K., Squires, K.C., and Hillyard, S.A. (1975) Two varieties of long latency positive waves evoked by unpredictable auditory stimuli in man. Electroencephalography and Clinical Neurophysiology, 38, 387-401.

Studdert-Kennedy, M., Liberman, A.M., Harris, K.S., and Cooper, F.S. (1970). Motor theoru of speech perception: A reply to Lane's critical review. Psychology Review, 77, 234-249.

Synder, E., and Hillyard, S. (1976). Long latency evoked potentials to irrelevant, deviant stimuli. Behavioral Biology, 16, 319-331.

Winkler, I., Reinikainen, K., and Naatanen, R. Event- related brain potentials reflect traces of echoic memory in humans. Perception and Psychophysiology, 53, 443-449.

APPENDICES

APPENDIX A

RAW DATA FOR INDIVIDUAL SUBJECTS

SUBJECT RAW DATA
POINT TO POINT MEASURES

		FREQUENT			DEVIANT			FREQUENT			DEVIANT		
SUBJECT	CONDITION	MMN LATENCY	MMN RAW NUMBER	MMN BTP	MMN LATENCY	MMN RAW NUMBER	MMN BTP	P3 LATENCY	P3 RAW NUMBER	P3 BTP	P3 LATENCY	P3 RAW NUMBER	P3 BTP
01	1	320	1968	-053	320	1959	-043	390	1998	-023	390	2061	+059
	2	330	1983	-028	330	1935	-085	490	2032	+024	490	2084	+064
	3	340	1957	-857	340	1965	-043	450	2014	+013	450	2033	+025
	4	360	1970	-048	360	1948	-068	440	2016	+002	440	2059	+043
02	1	360	1970	-035	360	1952	-052	470	2010	+005	470	2025	+021
	2	350	1979	-023	350	1951	-049	470	2006	+004	470	2059	+059
	3	430	2001	+001	430	1980	-018	530	2022	+022	530	2046	+048
	4	350	1991	-001	350	1979	-019	600	2019	+032	600	2036	+038
03	1	330	2015	+015	330	1983	-036	490	2000	-007	490	2040	+021
	2	440	1993	-011	440	1946	-060	480	2007	+003	480	2010	+004
	3	270	2021	+034	270	1949	-043	340	1988	-005	340	2016	+024
	4	390	1988	-019	390	1949	-072	470	1936	+072	470	2051	+050
04	1	360	1995	-018	360	1972	-065	460	1992	-015	460	2034	+014
	2	280	2012	+029	280	1964	-020	390	1985	-049	390	2032	+036
	3	380	1993	-024	380	1960	-053	490	2013	-013	490	2044	+031
	4	380	1991	-022	380	1934	-102	530	1992	-020	590	2048	+029
05	1	360	1952	-055	360	1880	-119	430	2023	+016	430	2064	+065
	2	260	2022	-028	260	1930	-080	320	2038	+044	320	2125	+117
	3	380	1934	-078	380	1886	-093	570	2038	+026	570	2220	+241
	4	390	1945	-070	390	1781	-238	590	2072	+057	590	2256	+237
06	1	320	1808	-161	320	1766	-195	440	1970	+001	440	2146	+185
	2	300	1854	-092	300	1803	-150	430	1873	-073	430	2009	+056
	3	380	1982	+083	380	1679	-308	530	1893	-006	530	2109	+122
	4												

SUBJECT RAW DATA
POINT TO POINT MEASURES

		FREQUENT			DEVIANT			FREQUENT			DEVIANT		
SUBJECT	CONDITION	MMN LATENCY	MMN RAW NUMBER	MMN BTP	MMN LATENCY	MMN RAW NUMBER	MMN BTP	P3 LATENCY	P3 RAW NUMBER	P3 BTP	P3 LATENCY	P3 RAW NUMBER	P3 BTP
07	1	310	1885	-103	310	1873	-129	420	2002	+019	420	2084	+084
	2	320	1934	-052	320	1854	-116	500	1983	-003	500	2036	+067
	3	350	1895	-069	350	1880	-130	560	2004	+060	560	2050	+040
	4	330	1933	-040	330	1855	-152	450	2002	+029	450	2070	+064
08	1	360	1912	-041	360	1894	-008	420	1957	+004	420	2023	+121
	2	380	1917	-031	380	1910	-058	430	1983	+035	430	2033	+065
	3	380	1916	-031	380	1877	-047	430	1968	+021	430	2064	+140
	4	400	1961	+007	400	1848	-119	500	2007	+053	500	2130	+163
09	1	340	1871	-071	340	1808	-138	440	1917	-025	440	1991	+046
	2	270	1886	-083	270	1875	-042	380	1905	-064	380	1962	+045
	3	360	1885	-034	360	1816	-126	510	1902	-017	510	1930	-008
	4	360	1902	-054	360	1822	-126	500	1956	-046	500	1984	+037
10	1	320	1928	-033	320	1813	-188	440	1965	+006	440	2000	+001
	2	370	1934	-042	370	1810	-168	570	1910	-066	570	2074	+096
	3	370	1925	-001	370	1832	-148	460	1940	+014	460	2008	+028
	4	390	1941	-033	390	1809	-196	500	1918	-056	500	2009	+004
11	1	290	1897	-116	290	1883	-094	370	2011	-024	370	2020	+039
	2	280	1931	-017	280	1886	-050	360	2009	+061	360	2175	+239
	3	250	1941	-022	250	1891	-070	300	1870	-093	300	2001	+040
	4	270	1953	+006	270	1941	-025	300	1934	-013	300	2032	+066
12	1	300	1969	-009	300	1846	-138	390	1954	-024	390	1991	+007
	2												
	3	250	2002	+001	250	1827	-144	290	1906	-095	290	1989	+021
	4	360	1941	-038	360	1818	-106	450	1973	+006	450	1991	+067

SUBJECT RAW DATA
POINT TO POINT MEASURES

		FREQUENT			DEVIANT			FREQUENT			DEVIANT		
SUBJECT	CONDITION	MMN LATENCY	MMN RAW NUMBER	MMN BTP	MMN LATENCY	MMN RAW NUMBER	MMN BTP	P3 LATENCY	P3 RAW NUMBER	P3 BTP	P3 LATENCY	P3 RAW NUMBER	P3 BTP
13	1	280	1920	-036	280	1784	-204	380	1985	+029	380	2050	+062
	2	280	1826	-146	280	1712	-250	370	2019	+047	370	2056	+094
	3	230	2028	+080	230	1849	-076	280	1922	-026	280	1982	+059
	4	240	1984	+033	240	1935	-013	300	1837	-114	300	2008	+088
14	1	240	2009	+089	240	1883	-085	320	1991	+071	320	2024	+056
	2	260	1952	+047	260	1880	-068	400	1945	+040	400	2016	+068
	3												
	4												
15	1	290	1937	+018	290	1867	-076	320	1903	-016	320	1963	+020
	2	280	1893	-029	280	1839	-110	440	1915	-007	440	1990	+045
	3	370	1874	-061	370	1779	-158	470	1902	-031	470	1952	+015
	4	350	1909	-016	350	1873	-051	420	1907	-018	420	1926	+002
16	1	250	1892	-014	250	1771	-139	420	1883	-023	420	1953	+043
	2	260	1916	-004	260	1812	-104	420	1903	-017	320	1945	+029
	3	210	1946	+040	210	1775	-121	290	1890	-016	290	1955	+061
	4												
17	1	340	1833	-176	340	1765	-189	410	1822	-127	410	1967	+017
	2	320	1879	-055	320	1786	-145	520	1945	+011	520	2010	+079
	3	240	2025	+081	240	1873	-023	290	1936	-009	290	2024	+128
	4	250	1915	-015	250	1860	-076	290	1910	-020	290	1916	-020
18	1	320	1823	-065	320	1702	-227	450	1868	-020	450	1918	-011
	2	280	1847	-073	280	1791	-083	390	1869	-051	390	1966	+092
	3	250	1970	+038	250	1860	-052	300	1879	-053	300	1974	+062
	4	230	1977	+081	230	1869	-025	290	1880	-016	290	1960	+066

SUBJECT RAW DATA
POINT TO POINT MEASURES

		FREQUENT			DEVIANT			FREQUENT			DEVIANT		
SUBJECT	CONDITION	MMN LATENCY	MMN RAW NUMBER	MMN BTP	MMN LATENCY	MMN RAW NUMBER	MMN BTP	P3 LATENCY	P3 RAW NUMBER	P3 BTP	P3 LATENCY	P3 RAW NUMBER	P3 BTP
19	1	270	2074	+004	270	2031	-061	300	2067	-003	300	2051	-040
	2	260	2014	-038	260	2018	-002	330	2001	-025	330	2075	+055
	3	250	2071	+011	250	2033	-009	280	2060	+000	280	2064	+022
	4	240	2048	-013	240	2015	-050	280	2038	-023	280	2090	+025
20	1												
	2	360	1925	-056	360	1844	-167	420	1914	-067	420	1901	-030
	3	360	1922	-032	360	1858	-162	450	1963	+009	450	2096	+078
	4	260	1996	+031	200	1862	-148	290	1945	-020	290	2032	+022
21	1	480	1910	-003	480	1868	-019	570	1969	+056	570	1982	+095
	2	330	1942	-001	330	1848	-079	530	1901	-042	530	2011	+084
	3	380	1893	-041	380	1824	-124	580	1943	+009	580	2032	+087
	4	410	1895	-024	410	1866	-030	490	1914	-005	490	1977	+081
22	1	290	1865	-079	290	1791	-151	410	1917	-027	410	1989	+049
	2	280	1834	-035	280	1670	-259	380	1967	+073	389	2042	+113
	3	250	1981	+009	250	1922	-049	300	1888	-084	300	1987	+016
	4	350	1895	-052	350	1811	-107	300	1994	+047	400	1946	+022
23	1	380	1850	-058	380	1835	-078	490	1848	-060	490	1910	+005
	2	390	1842	-062	390	1811	-063	540	1885	-019	540	1960	+086
	3	240	1989	+084	240	1832	-086	300	1901	-004	300	1925	+007
	4	210	1985	+082	210	1845	-085	290	1917	+014	290	1947	+017
24	1	280	1882	-065	280	1758	-175	370	1959	+012	370	2003	+070
	2	390	1842	-062	390	1811	-063	540	1885	-019	540	1960	+086
	3	240	1989	+084	240	1832	-086	300	1901	-004	300	1925	+007
	4	220	1977	+074	220	1845	-085	290	1917	+014	290	1947	+017

SUBJECT RAW DATA
POINT TO POINT MEASURES

SUBJECT	CONDITION	FREQUENT MMN LATENCY	FREQUENT MMN RAW NUMBER	FREQUENT MMN BTP	DEVIANT MMN LATENCY	DEVIANT MMN RAW NUMBER	DEVIANT MMN BTP	FREQUENT P3 LATENCY	FREQUENT P3 RAW NUMBER	FREQUENT P3 BTP	DEVIANT P3 LATENCY	DEVIANT P3 RAW NUMBER	DEVIANT P3 BTP
25	1	280	2014	+038	280	1973	+019	430	1958	-018	430	2053	+099
	2	360	1952	-019	360	1894	-097	450	1976	+006	450	2013	+022
	3	350	1930	-038	350	1901	-050	580	1995	+033	580	2045	+094
	4	380	1923	-035	380	1881	-116	630	2003	+045	630	2034	+040
26	1	270	2013	-020	270	1899	-104	540	2065	+032	540	2161	+158
	2	310	1892	-009	310	1839	-120	430	2029	+028	430	2142	+183
	3	340	1927	-034	340	1822	-100	570	2010	+049	570	2264	+342
	4	360	1931	-020	360	1857	-141	420	2061	+110	420	2066	+066
27	1	280	1912	-089	280	1832	-158	590	2008	+007	590	2091	+103
	2	300	1886	-132	300	1715	-272	540	1886	+001	540	2139	+152
	3	400	2033	+041	400	1778	-152	580	2022	+030	580	2122	+192
	4	240	2039	+057	240	1839	-201	330	1890	-092	330	2072	+032

SUBJECT RAW DATA
GREATEST PEAK MEASURES

		FREQUENT			DEVIANT			FREQUENT			DEVIANT		
SUBJECT	CONDITION	MMN LATENCY	MMN RAW NUMBER	MMN BTP	MMN LATENCY	MMN RAW NUMBER	MMN BTP	P3 LATENCY	P3 RAW NUMBER	P3 BTP	P3 LATENCY	P3 RAW NUMBER	P3 BTP
01	1	320	1968	-053	320	1959	-043	410	2009	-012	390	2061	+059
	2	310	1973	-035	330	1935	-085	510	2047	+024	490	2084	+064
	3	340	1957	-058	340	1965	-043	470	2031	+016	460	2033	+025
	4	330	1961	-057	360	1948	-068	500	2034	+016	440	2059	+043
02	1	340	1965	-040	360	1952	-052	480	2012	+007	470	2025	+021
	2	320	1973	-029	350	1951	-049	510	2010	+006	470	2059	+059
	3	330	1969	-031	330	1987	-011	600	2041	+041	530	2046	+048
	4	280	1972	-020	350	1979	-019	550	2024	+032	600	2036	+038
03	1	420	1965	-035	330	1983	-036	530	2015	+015	490	2040	+021
	2	350	1977	-027	380	1953	-060	490	2010	+006	480	2010	+004
	3	360	1974	-019	270	1949	-043	400	2009	+016	340	2016	+024
	4	360	1988	-019	390	1949	-072	410	2017	+010	470	2051	+030
04	1	380	1983	-028	280	1969	-065	420	2004	-007	460	2019	-014
	2	360	1968	-069	270	1973	-020	400	1996	-041	390	2029	+036
	3	360	1983	-039	360	1952	-055	490	2009	-013	490	2037	+031
	4	350	1982	-030	380	1918	-102	590	2019	+007	590	2048	+029
05	1	340	1945	-064	360	1880	-119	450	2047	+040	430	2064	+065
	2	270	2013	-019	260	1930	-080	320	2038	+044	320	2125	+117
	3	350	1911	-101	380	1886	-092	550	2064	+052	570	2220	+241
	4	370	1928	-087	390	1781	-238	550	2116	+094	590	2256	+237
06	1	340	1771	-198	320	1766	-195	420	2023	+054	440	2146	+185
	2	340	1813	-133	300	1803	-150	390	1874	-068	430	2009	+056
	3	320	1865	-067	370	1678	-309	390	1985	+086	530	2109	+122
	4												

SUBJECT RAW DATA
GREATEST PEAK MEASURES

		FREQUENT			DEVIANT			FREQUENT			DEVIANT		
SUBJECT	CONDITION	MMN LATENCY	MMN RAW NUMBER	MMN BTP	MMN LATENCY	MMN RAW NUMBER	MMN BTP	P3 LATENCY	P3 RAW NUMBER	P3 BTP	P3 LATENCY	P3 RAW NUMBER	P3 BTP
07	1	320	1880	-103	320	1871	-129	440	2005	+023	420	2084	+084
	2	290	1912	-074	320	1854	-116	480	1983	-003	490	2037	+067
	3	320	1888	-076	350	1880	-130	590	2021	+057	560	2050	+040
	4	310	1899	-074	340	1854	-152	460	2012	+039	450	2070	+064
08	1	370	1891	-063	360	1894	-008	430	1964	+011	420	2023	+121
	2	370	1907	-041	380	1910	-058	440	1992	+044	430	2033	+065
	3	380	1916	-031	380	1877	-047	460	1998	+051	430	2064	+140
	4	350	1906	-048	400	1848	-119	490	2012	+058	500	2130	+163
09	1	350	1867	-075	340	1808	-138	460	1932	-010	420	1992	+046
	2	270	1886	-083	270	1875	-042	440	1928	-041	440	1990	+073
	3	340	1868	-051	370	1815	-126	420	1948	+029	500	1933	-008
	4	340	1882	-075	360	1822	-126	450	1946	+011	500	1984	+037
10	1	300	1896	-065	320	1813	-188	410	1978	+017	440	2000	+001
	2	400	1923	-053	370	1810	-168	430	1945	-030	440	1934	-044
	3	340	1923	-003	370	1832	-148	390	1955	-029	460	2008	+028
	4	340	1925	-049	380	1807	-198	390	1941	-033	480	2006	+001
11	1	290	1897	-116	290	1883	-094	360	2017	+019	370	2020	+039
	2	310	1879	-069	280	1886	-050	370	2020	+072	360	2175	+239
	3	290	1864	-099	250	1891	-070	350	1957	-006	300	2001	+040
	4	320	1893	-054	270	1941	-041	380	1995	+048	300	2032	+066
12	1	320	1928	-050	300	1846	-138	380	1972	-006	390	1991	+007
	2												
	3	300	1902	-099	240	1822	-149	320	1915	-086	290	1989	+021
	4	300	1882	-097	370	1822	-106	440	1982	+003	450	1991	+067

SUBJECT RAW DATA
GREATEST PEAK MEASURES

		FREQUENT			DEVIANT			FREQUENT			DEVIANT		
SUBJECT	CONDITION	MMN LATENCY	MMN RAW NUMBER	MMN BTP	MMN LATENCY	MMN RAW NUMBER	MMN BTP	P3 LATENCY	P3 RAW NUMBER	P3 BTP	P3 LATENCY	P3 RAW NUMBER	P3 BTP
13	1	290	1914	-042	280	1784	-204	430	2002	+033	380	2050	+062
	2	290	1817	-155	280	1712	-250	430	2042	+070	370	2056	+094
	3	300	1894	-054	220	1849	-076	380	2006	+058	280	1982	+059
	4	300	1837	-114	240	1935	-013	390	2011	+060	300	2008	+088
14	1	270	1958	+038	240	1883	-085	340	1999	+079	370	2032	+064
	2	320	1924	-019	260	1880	-068	400	1945	+040	400	2016	+068
	3												
	4												
15	1	340	1888	-031	290	1867	-076	410	1937	+018	330	1955	+020
	2	310	1871	-051	320	1835	-110	450	1918	-004	440	1990	+045
	3	370	1874	-061	370	1779	-158	480	1910	-023	470	1952	+015
	4	290	1900	-025	350	1873	-051	400	1926	+001	430	1924	+000
16	1	300	1848	-058	250	1771	-139	350	1889	-017	330	1905	-005
	2	300	1886	-002	260	1812	-104	360	1912	-008	320	1945	+029
	3												
	4												
17	1	360	1786	-163	340	1765	-189	480	1914	-035	480	2012	+062
	2	340	1861	-075	320	1786	-145	520	1945	+011	520	2010	+079
	3	320	1878	-067	240	1873	-023	340	1904	-041	290	2024	+128
	4	260	1895	-035	250	1860	-076	290	1910	-020	290	1916	-020
18	1	330	1804	-084	320	1702	-227	480	1886	-002	450	1918	-011
	2	310	1833	-087	280	1791	-083	370	1907	-013	390	1966	+092
	3	370	1828	-112	250	1860	-052	450	1875	-057	300	1974	+062
	4	330	1832	-064	230	1869	-025	370	1875	-021	290	1960	+066

SUBJECT RAW DATA
GREATEST PEAK MEASURES

		FREQUENT			DEVIANT			FREQUENT			DEVIANT		
SUBJECT	CONDITION	MMN LATENCY	MMN RAW NUMBER	MMN BTP	MMN LATENCY	MMN RAW NUMBER	MMN BTP	P3 LATENCY	P3 RAW NUMBER	P3 BTP	P3 LATENCY	P3 RAW NUMBER	P3 BTP
19	1	360	2033	-037	270	2031	-061	410	2047	-023	300	2051	-040
	2	430	1948	-091	260	2018	-002	520	2049	+010	330	2075	+055
	3	410	2014	-046	250	2033	-009	540	2079	+019	280	2064	+022
	4	270	2036	-025	240	2015	-050	310	2050	-011	280	2090	+025
20	1												
	2	270	1911	-070	360	1844	-167	300	1944	-037	420	1981	-030
	3	350	1909	-045	360	1858	-162	450	1963	+009	450	2096	+078
	4	270	1928	-037	200	1862	-148	300	1955	-010	290	2032	+022
21	1	410	1887	-026	480	1868	-019	450	1913	+000	570	1982	+095
	2	430	1850	-093	330	1848	-079	520	1906	-037	530	2011	+084
	3	400	1889	-045	380	1824	-124	490	1944	+010	580	2032	+087
	4	420	1888	-032	410	1866	-030	510	1926	+007	490	1977	+081
22	1	310	1827	-117	290	1791	-151	380	1962	+018	410	1989	+049
	2	300	1793	-176	280	1670	-259	400	1983	+014	380	2042	+113
	3	320	1866	-106	250	1922	-049	410	1956	-016	300	1987	+016
	4	320	1801	-146	350	1811	-107	400	1994	+047	400	1936	+022
23	1	450	1813	-095	380	1835	-078	490	1848	-060	490	1910	+005
	2	410	1831	-073	390	1811	-063	450	1892	-012	540	1960	+086
	3	370	1844	-068	240	1832	-086	580	1892	-013	300	1925	+007
	4	360	1852	-051	210	1845	-085	430	1869	-034	290	1947	+017
24	1	300	1879	-068	280	1758	-175	400	2025	+078	370	2003	+070
	2	410	1831	-073	390	1811	-063	560	1894	-010	540	1960	+086
	3	350	1844	-061	240	1832	-086	500	1867	-038	300	1925	+007
	4	360	1852	-051	220	1845	-085	430	1869	-034	290	1947	+017

SUBJECT RAW DATA
GREATEST PEAK MEASURES

		FREQUENT			DEVIANT			FREQUENT			DEVIANT		
SUBJECT	CONDITION	MMN LATENCY	MMN RAW NUMBER	MMN BTP	MMN LATENCY	MMN RAW NUMBER	MMN BTP	P3 LATENCY	P3 RAW NUMBER	P3 BTP	P3 LATENCY	P3 RAW NUMBER	P3 BTP
25	1	360	1888	-088	280	1973	+019	440	1968	-008	430	2053	+099
	2	360	1952	-019	360	1894	-097	450	1976	+006	450	2013	+022
	3	330	1922	-040	350	1901	-050	560	1991	+029	580	2045	+094
	4	360	1904	-054	380	1881	-116	600	2011	+053	630	2034	+040
26	1	320	1937	-096	270	1899	-104	520	2093	+060	540	2161	+158
	2	340	1840	-161	310	1839	-120	410	2046	+045	430	2142	+183
	3	320	1911	-050	340	1822	-100	520	2114	+153	570	2264	+342
	4	350	1916	-035	360	1857	-141	510	2008	+137	420	2066	+066
27	1	300	1863	-138	280	1832	-158	500	2073	+072	590	2091	+103
	2	300	1886	-132	300	1715	-272	480	2050	+032	540	2139	+152
	3	310	1898	-094	400	1778	-152	390	2035	+043	580	2122	+192
	4	310	1862	-120	240	1839	-201	540	2060	+078	330	2072	+032

APPENDIX B

PILOT STUDY

PILOT STUDY

A pilot study was conducted to determine the best methods and procedures for the ERP experiment.

1. Subjects: Three adult female volunteers ages 22, 24, and 31 participated in the study. All three subjects had normal puretone hearing thresholds (determined by the investigator), were right handed (Edinburgh Handedness Inventory), and had no known neurological, cognitive, or learning deficits (verbal confirmation by the subject).

2. Stimuli: The same speech stimuli pairs were utilized from the labeling and ABX discrimination tasks with the addition of one pair consisting of the endpoints. The stimuli were generated with four pairs of stimuli chosen for the ERP experiment as follows: two within category pairs and two across category pairs. The 30 ms prevoicing and the 0 ms VOT were identified as within the same category /ba/ and the 30 and 60 ms VOT stimuli were identified as within the same category /pa/. The 0 ms and 30 ms VOT pair was chosen to represent across or different categories, /ba/ and /pa/ respectively, so that three pairs of stimuli differed by 30 ms. The endpoint across category pair consisted of the -30 ms VOT /ba/ and 60 ms VOT /pa/

differing in VOT by 90 ms. An "oddball paradigm" was used in each pair with a deviant probability of occurrence 20%. In the within category /ba/ and across category /ba/ /pa/ the 0 ms VOT stimulus was used as the deviant. The 30 ms VOT stimuli was the deviant in the 30/60 ms pair and the 60 ms VOT stimuli was the deviant in the endpoint pair. Interstimulus interval was 1500 ms onset to onset. The stimuli were passed through a 1500 low pass filter to eliminate a perceived bleed through present in the playback. Evoked responses to 40 deviant and 160 frequent stimuli made up a single trial block in an attend task. Evoked responses to 80 deviant and 320 frequent stimuli made up a single trial block in an ignore task. This is the upper limit of the number of stimuli the EPACS software can average. Most studies on the MMN are made in an ignore condition and usually average approximately 1000 stimuli. Studies on the P3 are usually in an attend condition with as few as 100 stimuli. (See review of attentional affects on evoked potentials.) The four trial blocks containing the four stimulus pairs were randomly presented to each subject.

3. Methods and Procedures: ERP's were recorded from 6 mm cup disk surface electrodes with protected leads (F-E5 GH) placed on the scalp at the frontal zenith (Fz), central zenith (Cz), parietal zenith (Pz), and left/right parietal (P3/P4) locations according to the International 10-20 system, with

linked reference electrodes on both ears and a forehead ground. Acceptable impedance measures were 5K ohms or less for each electrode and no more than a 5K ohm difference between any two electrodes. The recording window included a 100 ms prestimulus period and 700 ms of post-stimulus time. Stimuli were presented via earphones at 70 dB at ear level. In the attend task subjects were asked to push a button to the infrequent stimuli, i.e., when they hear one that is different. In the ignore task subjects were asked to read silently to divert attention from the stimuli. The electrodes were attached to Isolation/Amplifiers (Grass units P511k) with their own power supply (Grass RPS107). Frequency range settings were from .1 to 30 Hz. Mounted oscilloscopes were used for visual monitoring of the signals. The amplified analog signals were passed through an additional low pass (45Hz) filter and then through an analog-to-digital benchtop converter (Metaresearch). The digital signals were stored and analyzed in a Macintosh SE microcomputer. Following the test procedure, the electrode impedances were checked again.

4. Component identification and measurement:

a. Averaged waveforms for the infrequent and frequent stimuli in each of the four phonetic conditions in the attend and ignore tasks to identify the MMN and/or P300 were visually inspected. Operational definition of the

MMN was a relative negativity following the N1 (which was apparent in the standard and deviant wave forms) in the latency range of 200+ ms. Operational definition of the P3 was the greatest relative positivity in the latency of 300+ ms.

b. Three different measures for each component in the frequent and infrequent averaged waveforms were obtained. There is no standard systematic method of measuring components (Hall, 1992), therefore three measures were taken for possible findings. 1) A cursor was placed on the point of greatest peak and the raw number corresponding to microvolts was recorded; 2) A cursor was placed on the point of greatest peak and the baseline to peak (BTP) number was recorded. The EPACS software program obtains an average of the entire waveform to represent a base which is subtracted from each point in time; 3) A peak to peak (PTP) measure was obtained by placing one cursor on the peak preceding each component and one cursor on the peak of the component and recording the peak to peak measure from the EPACS analysis system (P2 to MMN and MMN to P3). Subtraction of the frequent measurements from the infrequent measurements yielded a difference score. If the MMN difference score was a negative number (i.e. the infrequent measure is less than the frequent measure) then the component was considered identified

in that condition. If the P3 difference score was a positive number (i.e. the infrequent measure is greater than the frequent measure) then the P3 was considered identified.

6. Results: Results of the pilot study indicated that the ignore task produced the components of interest (MMN and P3) with greater frequency than the attend task. The components were identified 63 out of 72 measures in the ignore task with the average of 400 trials as opposed to 51 out of 72 measures in the attend task with the average of 200 trials. Visual inspection of waveforms in the six locations indicated that the Fz and Cz locations consistently produced the clearest waveforms and upon further inspection were very similar in morphology. The Cz location appeared to have a trend of slightly larger overall amplitudes than the Fz. Trends in latency and amplitude across conditions were more difficult to determine with the small number of subjects. The average MMN and P3 measures were larger across categories than within categories. Two of the three subjects had MMN latencies earliest for the within /ba/ stimulus pair and latest for within /pa/ stimulus pair. Two subjects also had the longest P3 latency in the extreme across category pair.

7. Conclusions: In conclusion, the ignore task with 400 trials was preferable to obtain the MMN and P3 components. The Fz and Cz locations appeared to yield waveforms with lower signal to noise ratios. In general, it appeared that across categories had larger amplitudes than the within categories on the MMN and P3 components

APPENDIX C

10-20 SYSTEM

10-20 SYSTEM

In this procedure electrode sensors are placed on the subject's head in specified locations according to the 10-20 system (Jasper, 1958). The "10" and the "20" refer to percentages of distance from specific reference points on the human head. The intent is to locate recording sites over areas of the brain which would be consistent for different laboratories and overlying the same functional locations in children or adults regardless of the size of the head. Measurements are made (in centimeters) anteriorally from the nasion, or bridge of the nose, across the top of the head posteriorally to the inion, a notch at the back of the head. From one side of the head to the other the reference is the pre-auricular notch (a notch in the bone at the front of the ear canal). Locations are indicated with a letter (for the brain lobe) and a number. Even numbers designate the right side and odd numbers designate the left side of the brain. For example in the anterior-posterior direction 10 percent up from the nasion is the Frontal pole (10 percent to the left and 10 percent to the right is Fp2), 20 percent more on the anterior-posterior line (30 percent of the total distance) is the Frontal Zenith (Fz), plus 20 percent (50 percent of the total) is the Central Zenith (Cz), plus 20 percent is the Parietal Zenith (Pz), and 20

percent more is the Occipital Zenith (Oz) which is 10 percent anterior to the inion. The mid-point of the line from one pre-auricular notch across the top of the head to the opposite ear pre-auricular notch will intersect with the anterior-posterior line at the Cz location. Ten percent of this distance up from the left ear reference will be T3 (for left Temporal lobe), 20 percent more is C3 (Central lobe), etc.. Twenty one potential sites are locatable in this way.

VITA

Martha Ann Stokes was born April 26, long ago in Gulfport, Mississippi. After graduating High School in 1972, she went to the University of Southern Mississippi for the next five years earning her Master of Science degree in Speech and Hearing Science. She practiced speech pathology for the next twelve years on the Mississippi Gulf Coast. Middle age crisis hit and she decided to join the United States Air Force to become a bit more cosmo. After working at Wilford Hall Medical Center for three years she was selected to attend an Out-Service Training Program sponsored by the Department of the Air Force for a Ph.D in speech pathology. She chose the University of Tennessee and received her Ph.D in August, 1995. The best decision she ever made. She is now under orders to the Mississippi Gulf Coast as Director of Speech Pathology at Keesler Air Force Medical Center. Looks like full circle.